National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

A Natural Resource Condition Assessment for Sequoia and Kings Canyon National Parks

Appendix 1 - Landscape Context

Natural Resource Report NPS/SEKI/ NRR—2013/665.1

ON THE COVER
Giant Forest, Sequoia National Park
Photography by: Brent Paull

A Natural Resource Condition Assessment for Sequoia and Kings Canyon National Parks

Appendix 1 - Landscape Context

Natural Resource Report NPS/SEKI/ NRR—2013/665.1

James Thorne
Dept. of Environmental Science & Policy
John Muir Institute of the Environment
University of California
Davis, CA 95616

William B. Monahan
National Park Service
Inventory and Monitoring Division
1201 Oakridge Drive, Suite 150
Fort Collins, CO 80525

Andrew Holguin
Information Center for the Environment
1 Shields Avenue
University of California
Davis, CA 95616

Mark Schwartz
Dept. of Environmental Science & Policy
John Muir Institute of the Environment
University of California
Davis, CA 95616

June 2013

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

The National Park Service, Natural Resource Stewardship and Science office in Fort Collins, Colorado, publishes a range of reports that address natural resource topics. These reports are of interest and applicability to a broad audience in the National Park Service and others in natural resource management, including scientists, conservation and environmental constituencies, and the public.

The Natural Resource Report Series is used to disseminate high-priority, current natural resource management information with managerial application. The series targets a general, diverse audience, and may contain NPS policy considerations or address sensitive issues of management applicability.

All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner.

This document contains subject matter expert interpretation of the data. The authors of this document are responsible for the technical accuracy of the information provided. The parks refrained from providing substantive administrative review to encourage the experts to offer their opinions and ideas on management implications based on their assessments of conditions. Some authors accepted the offer to cross the science/management divide while others preferred to stay firmly grounded in the presentation of only science-based results. While the authors' interpretations of the data and ideas/opinions on management implications were desired, the results and opinions provided do not represent the policies or positions of the parks, the NPS, or the U.S. Government.

This report is available in digital format from the Natural Resource Publications Management website (http://www.nature.nps.gov/publications/nrpm/).

Please cite this publication as:

Thorne, J., W. B. Monahan, A. Holguin, and M. Schwartz. 2013. A natural resource condition assessment for Sequoia and Kings Canyon National Parks: Appendix 1 - landscape context. Natural Resource Report NPS/SEKI/NRR—2013/665.1. National Park Service, Fort Collins, Colorado.

NPS 102/120975, June 2013

Contents

Page

Contents (continued)

Figures

Page

Figures (continued)

Page

Figures (continued)

Page

Tables

Tables (continued)

Page

Scope of analysis

We assessed landscape elements of the Sequoia and Kings Canyon National Parks (SEKI NP or SEKI or the Parks) from the context of the ecological region that comprises the southern Sierra Nevada. The goals of this chapter are to identify the relative contributions, or unique values, of natural resources that the Parks provide within the region; and, to evaluate landscape level threats to the Parks. To these ends, this chapter predominantly presents data that can be summarized across the whole region, and asks two questions. 1) "For each landscape element, what is the relative contribution that the Parks make to the overall region?" 2) "For focal landscape elements (e.g., fragmentation, human encroachment) what are the landscape level threats to the Parks?" The chapter provides Sequoia and Kings Canyon National Parks with: (i) a series of context-setting maps and tables that address natural ecosystem elements, historic trends in climate and human affects; and (ii) an analysis of existing landscape dynamics data for areas within and surrounding the park. The chapter is also meant to be a reference for these data elements, and as such presents a large number of tables and figures, with the hope that these can provide a roadmap for later users to track down data for their own purposes.

In defining a landscape area for this chapter, we used the Protected Area Centered Ecosystem (PACE) boundary developed specifically for Sequoia, Kings Canyon, and Yosemite National Parks (Piekielek et al. 2010, Piekielek et al. 2011, Hansen et al. in press) as part of the Park Analysis for Monitoring Support (PALMS) project detailed below. The PACE boundary contains an ecologically meaningful area for landscape analysis that integrates a number of fundamentally important factors for the parks, including watershed boundaries, natural disturbances, and crucial and contiguous habitat for select species. Detailed methods associated with establishing PACE boundaries for this NRCA are described under the project overview for PALMS.

Critical questions

The critical landscape questions addressed here have to do with the extent to which SEKI NP is unique in the region, and how much SEKI contributes to regional natural attributes. We describe the natural resource condition of SEKI, at the landscape scale, according to three criteria: (a) the physical environment; (b) human land use factors; and (c) measures of potential conservation interest.

The physical environment includes the following factors: elevation; geology; minimum and maximum annual temperatures; precipitation; runoff; climatic water deficit (a measure of the degree of drought stress experienced by plants), vegetation type and cover; standing carbon; yearly variations in carbon produced; and water yield.

Measures of human land use include: land ownership; change in human populations around the parks; and change in housing density.

Additional measures of conservation interest include social, biotic, and physical/biotic interactions, specifically: the network of protected areas; connectivity between those protected areas and other habitat patches; the extent of fragmentation by human development; and the Fire

Return Interval Departure (FRID) index (a measure of the departure of vegetation from its natural fire cycle).

Critical questions are addressed in two ways. We describe the condition, and in some instances trend, for attributes inside the SEKI NP boundary and we describe how those conditions relate to the same measures outside the park, in the larger PACE boundary.

This chapter is meant to provide a broader spatial context from which content from other focal element chapters may be interpreted at a larger spatial scale. The detailed information provided in other chapters was frequently not available across the entire region, however patterns of those focal elements (e.g., biodiversity, air quality) may possibly be better interpreted when the ecoregional extent of factors that influence those elements is described.

Data sources and types used in analysis

For this chapter we used existing map data from a variety of sources, and summarized the information for the PACE and SEKI NP boundary areas. The data come primarily from two major sources: a University of California, Davis, effort to produce downscaled historic climate data for California, and a series of federal agencies and institutions that have produced regional assessments for the southern Sierra Nevada ecoregion. We first describe the climate processing that went into the downscaled climate variables, and then provide an overview of each of the major regional report/initiatives that we reviewed, and from which map data were selected for this report.

The Climate Data

US Geological Survey (USGS) researchers, Drs. Lorrie and Alan Flint, and Jim Thorne (UC Davis) have downscaled and bias corrected an historical data set of climate variables based on the 4 km PRISM climate surfaces (http://www.prism.oregonstate.edu/) to a 270 m horizontal resolution.

The 270 m grids represent historic climates from 1910 to 2000, and comprise 6,594,862 grid cells for California. Retaining yearly values for this region resulted in unwieldy large files. Therefore, we reduced the data to 30-year means, providing monthly blocks of variables historically for 1911-1940, 1941-1970, 1971-2000. These data were further processed by clipping to the PACE boundary for this study. The first data produced were minimum monthly temperature averaged annually (Tmin), maximum monthly temperature averaged annually (Tmax) and annual precipitation (Ppt) (Table 1).

Flint and Flint (Flint & Flint 2007) have developed a program to calculate eleven derivative climatic measures (Table 1) associated with water balance at the land surface. Calculation of these eleven derivative climatic values requires both static and time-varying input measures to create their Basin Characterization Model (BCM). The static inputs include: 1) a digital elevation model (DEM), 2) geology, 3) soil water content at field capacity, 4) soil porosity, 5) bulk bedrock permeability, 6) soil thickness, and 7) soil water content at wilting point. We used the BCM to produce this additional suite of variables state-wide at the 270 m grid scale.

The following table identifies all the variables produced. The variables listed in *italics* are the ones that were further used in this report (Table 1). Yearly values are calculated on a water year for California (i.e., October-September).

Table 1. Description of the 14 climatic variables downscaled to 270 m grid cell sizes for use in this chapter of the SEKI Natural Resources Condition Assessment.

Variable	Code	Creation Method	Units	Equation/model	Description
Maximum Temperature	tmax	downscaled	degree C	Model input	The maximum monthly temperature averaged annually
Minimum Temperature	tmin	downscaled	degree C	Model input	The minimum monthly temperature averaged annually
Precipitation	ppt	downscaled	mm	Model input	Total monthly precipitation (rain or snow) summed annually
Potential Evapotranspiration	pet	Modeled/ pre-processing input for BCM	mm	Modeled[1] on an hourly basis from solar radiation that is modeled using topographic shading, corrected for cloudiness, and partitioned on the basis of vegetation cover to represent bare-soil evaporation and evapotranspiration due to vegetation	Total amount of water that can evaporate from the ground surface or be transpired by plants summed annually
Runoff	run	BCM	mm	Amount of water that exceeds total soil storage + rejected recharge	Amount of water that becomes stream flow, summed annually
Recharge	rch	BCM	mm	Amount of water exceeding field capacity that enters bedrock, occurs at a rate determined by the hydraulic conductivity of the underlying materials, excess water (rejected recharge) is added to runoff	Amount of water that penetrates below the root zone, summed annually
Climatic Water Deficit	cwd	BCM	mm	pet-aet	Annual evaporative demand that exceeds available water, summed annually
Actual Evapotranspiration	aet	BCM	mm	pet calculated[2] when soil water content is above wilting point	Amount of water that evaporates from the surface and is transpired by plants if the total amount of water is not limited, summed annually
Sublimation	subl	BCM	mm	Calculated[3], applied to pck	Amount of snow lost to sublimation (snow to water vapor) summed annually
Soil Water Storage	stor	BCM	mm	ppt + melt – aet – rch - run	Average amount of water stored in the soil annually
Snowfall	snow	BCM	mm	precipitation if air temperature below 1.5 degrees C (calibrated)	Amount of snow that fell summed annually
Snowpack	pck	BCM	mm	Prior month pck + snow – subl - melt	Amount of snow that accumulated per month summed annually (if divided by 12 would be average monthly snowpack)
Snowmelt	melt	BCM	mm	Calculated[4], applied to pck	Amount of snow that melted summed annually (snow to liquid water)
Excess Water	exc	BCM	mm	ppt – pet	Amount of water that remains in the system, assuming evapotranspiration consumes the maximum possible amount of water, summed annually for positive months only

[1]Equation or model for variable available from the following publication:

Flint, A.L., Flint, L.E., Hevesi, J.A., and Blainey, J.M., 2004, Fundamental concepts of recharge in the Desert Southwest: a regional modeling perspective, in Groundwater Recharge in a Desert Environment: The Southwestern United States, edited by J.F. Hogan, F.M. Phillips, and B.R. Scanlon, Water Science and Applications Series, vol. 9, American Geophysical Union, Washington, D.C., 159-184.

[2]Equation or model for variable available from the following publication:

Flint, L.E., and Flint, A.L., 2007, Regional analysis of ground-water recharge, in Stonestrom, D.A., Constantz, J., Ferré, T.P.A., and Leake, S.A., eds., Ground-water recharge in the arid and semiarid southwestern United States: U.S. Geological Survey Professional Paper 1703, p. 29-59. http://pubs.usgs.gov/pp/pp1703/ http://pubs.usgs.gov/pp/pp1703/b/

[3]Equation or model for variable available from the following publication:

Flint, A.L., and Flint, L.E., 2007, Application of the basin characterization model to estimate in-place recharge and runoff potential in the Basin and Range carbonate-rock aquifer system, White Pine County, Nevada, and adjacent areas in Nevada and Utah: U.S. Geological Survey Scientific Investigations Report 2007-5099, 20 p. http://pubs.usgs.gov/sir/2007/5099/

The Regional Studies' Data

The SEKI region has been the subject of at least six major studies that each have different spatial extents, recorded information about different elements, and were prepared by varying groups with varying objectives (Table 2). We undertook a review of these reports, and evaluated which data to assemble for portrayal in this chapter. Criteria for inclusion were the applicability of the data to a resource condition assessment, the extent of each report's analysis, whether the data element covered the entire PACE region, and in cases where similar data were reported, which version was considered most applicable for the SEKI NP NRCA objectives.

The six previous studies often document the same elements. For example, we found five different regional maps of landcover among these six studies. In such cases we compared the maps to each other, and made a decision on which single version to include. We tried to defer to a version that SEKI NP currently uses. In some cases (e.g., standing carbon stock) we include both reported versions because both versions portray a different aspect of standing carbon.

Table 2. The five major sources of context – the source and which data are presented in maps or other format.

Title	Data Used
Park Analysis and Monitoring Support program & the Terrestrial Observation and Predictions System	PACE boundary, remotely sensed measures of primary productivity
NPScape	see Table 4
National Park Service Socio-economic Atlas	Population trends, housing density and road density as also reported by NPScape
NatureServe	Evaluated landcover map
Southern Sierra Partnership Report and The Nature Conservancy	Standing Carbon and Water Yield measures

Park Analysis and Monitoring Support (PALMS) program

The overall goal for the Park Analysis and Monitoring Support project (PALMS, Gross et al. in review) was to integrate NASA Earth System Science products, including especially those from the Terrestrial Observation and Predictions System (TOPS: http://ecocast.arc.nasa.gov/; Nemani et al. 2009), and other data sources into NPS landscape dynamics inventory and monitoring (I&M), initially at select pilot parks, and ultimately through providing methods more broadly across all natural resource parks. Sequoia, Kings Canyon, and Yosemite National Parks were included as pilot parks in PALMS. Specific PALMS objectives were to: (i) identify NPS Inventory and Monitoring (I&M) landscape dynamics indicators that could be readily and repeatedly computed from NASA and other related remotely sensed and GIS data; (ii) establish PACE boundaries appropriate for monitoring and informing park management decisions; (iii) add value to the data by analyzing past and future changes in select indicators; and (iv) deliver products, and mechanisms to use those products, within a decision-support framework for NPS managers.

The complete set of PALMS SEKI indicators and geospatial attributes of the data are summarized in Table 3. This suite of indicators includes components of weather and climate, land cover and land use, disturbances, primary production, and monitoring area (i.e., PACE). Complete descriptions of methodology and results are available in the descriptions of PALMS products (Nemani et al. 2009; Theobald et al. 2009; Theobald 2010; Bierwagen et al. 2010; Hansen et al. in press), including all the standard operating procedures (SOPs) available for download at http://science.nature.nps.gov/im/monitor/lulc/palms/index.cfm.

Protected Area Centered Ecosystem (PACE) Boundary Definition

Piekielek et al (2011) present a rationale for selecting protected areas centered ecoregional (PACE) boundaries. The PACE methods and philosophy are featured extensively throughout this landscape chapter because of the Parks management decision to select this as the basis for defining an ecologically meaningful landscape with respect to SEKI NP. PACE methods of analysis are reviewed here and explained in detail in Piekielek et al. (2011) and Hansen et al. (in press). In brief, the PACE boundary may be thought of as a spatial overlay of the major biotic and abiotic landscape features that are integral to understanding the relationship between a protected area, in this case SEKI, and its larger ecosystem. The PACE boundary used in this chapter was calculated in a series of steps that first define each landscape feature, then combine the results, and finally are adjusted post hoc to include additional expert knowledge that could not be factored explicitly into the original calculations:

Step 1: Define areas that are hydrologically connected to the park. Many focal resources and ecosystem process important to SEKI are mediated at landscape scales by surface water flow. The goal of this step was to evaluate and map the watersheds that are most important. The SEKI PACE for this criterion was defined according to standard hydrological unit codes (HUCs).

Step 2: Define areas that are necessary to preserve or maintain natural disturbance regimes. The goal of this step was to ensure that disturbances important to the park are evaluated and mapped at appropriate spatial scales. The SEKI PACE for this criterion was defined according to historical fire regimes.

Step 3: Define critical habitats for focal resources. The goal of this step was to ensure that all major habitats for key, defining park resources are evaluated and mapped to consider such factors as seasonal habitat, migration corridors, and metapopulation dynamics. The SEKI PACE boundary for this criterion was defined according to distributions of the great gray owl (*Strix nebulosa*) and Yosemite toad (*Bufo canorus*).

Step 4: Define contiguous habitat. Many park resources and ecosystem processes will necessarily be influenced by the amount and distribution of natural habitats. This step was based on well-established species-area relationships (for non-flying mammals) and an evaluation of natural habitats outside the park that are most similar to those within (based on park vegetation).

Step 5: Define edge effects of human activity. The goal of this step was to identify areas outside of SEKI where the effects of past and ongoing human activities may impact focal resources within the park. Human activities were defined based on converted or developed land cover classes, roads, trails, and census information. These influences were combined and buffered to signify their proximity effects on natural resources.

Step 6: Union the results from steps 1-5. This step was performed in order to simplify the different criterion boundaries into a single ecosystem boundary for use in defining areas of landscape analysis, like the one considered here in the NRCA.

Step 7 (optional; not included in the original PACE method): The PACE boundary defined in steps 1-6 was then examined and modified to include expert knowledge. Since the development of the original SEKI PACE, additional data and studies were completed and are relevant to further refinements of the boundaries. In particular, the Southern Sierra Partnership (SSP, described below) report presented the importance of connectivity south through the Transverse Ranges. Additionally, a small northern hump from the original PACE was eliminated to better reflect an ecological and management boundary recognized by multiple agencies in the Sierra Nevada. The final PACE used to define SEKI landscapes is shown in Figure 1.

Table 3. PALMS SEKI indicators and spatial resolution of the data.

Level	Category	Indicator	Resolution
Air and Climate	Weather and Climate	Phenology (Normalized difference vegetation analysis – NDVI), annual anomaly)	1 km (all); 8 & 16 day
		Climate gridded daily 2000-2008	1 km
		Climate scenarios (monthly)	12 km
Landscape dynamics	Land Cover	Ecosystem type composition Summary by spatial scale	30 m
		Connectivity/pattern of natural landscapes	270 m
	Extreme Disturbance Events	Fire effects via changes in phenology and related measures	1 km; monthly anomalies / persistent; annual trends
	Primary Production	Gross and Net primary productivity (via simulation model results)	1 km daily and/or monthly summaries
	Monitoring area	Greater park ecosystem boundaries (PACE)	30 m
	Land use	Land use	90 m

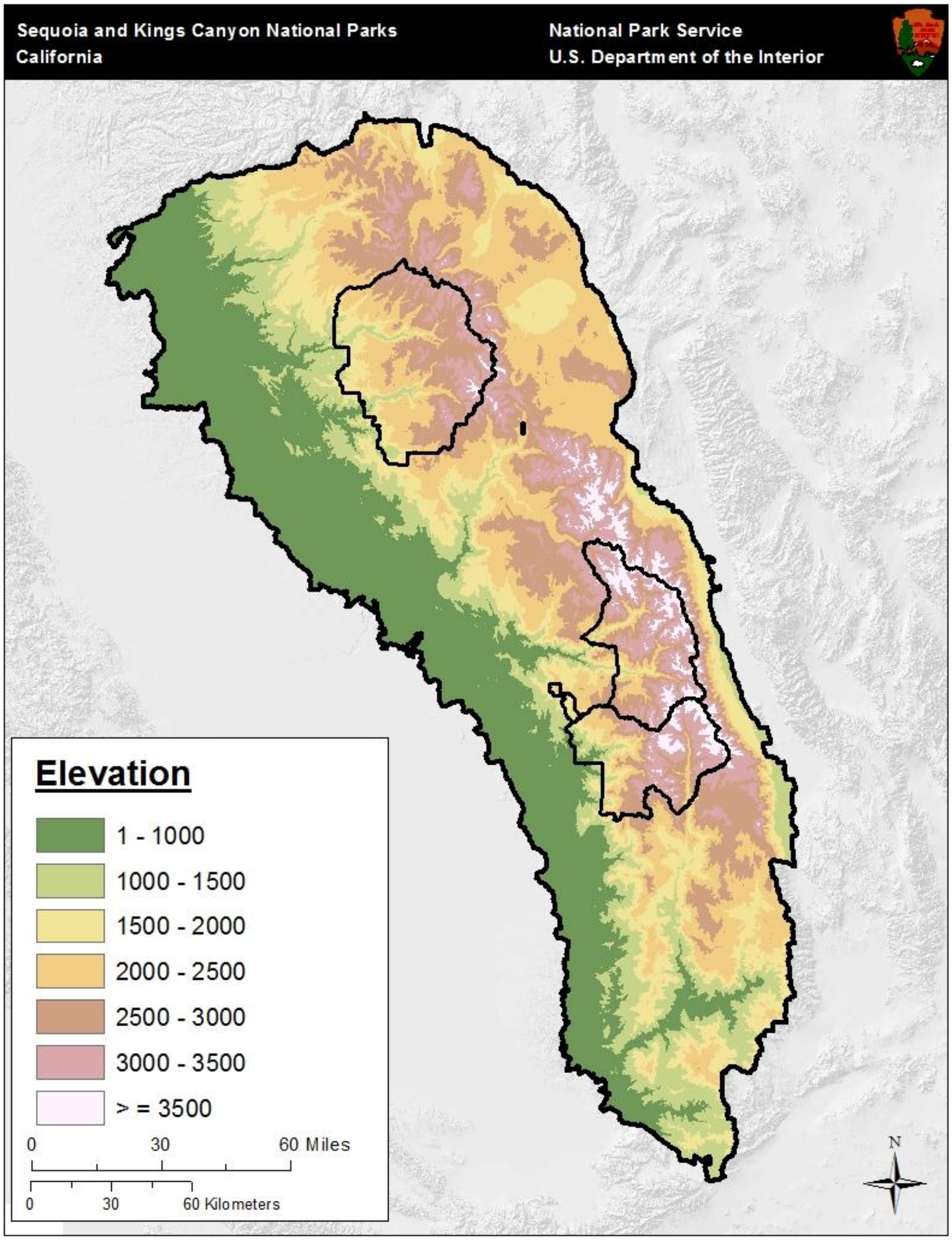


Figure 1. The Protected Area Centered Ecosystem (PACE) boundary for the Southern Sierra Nevada mountains used for the landscape ecology assessment of Sequoia and Kings Canyon National Parks (SEKI) showing the park boundaries for the aforementioned parks as well as Yosemite National Park. 500 m elevation bands are delineated using colors as defined in the figure legend.

NPScape

A primary source of support for standardized national-level NPS landscape dynamics monitoring of parks comes from NPScape (National Park Service 2011a), a project run by the Inventory and Monitoring (I&M) Division. The overall goal of NPScape is to support park natural resource management and planning by providing relevant landscape-scale information to all possible NPS units with significant natural resources (National Park Service 1999, National Academy of Public Administration 2010). Key NPScape objectives are to provide: (i) a coherent conceptual and analytical framework for conducting landscape-scale analyses and evaluations that can inform park-level decisions, (ii) credible methods that are well documented, founded on strong science, and readily repeatable and extensible with local data, (iii) informative and useful data and related products at the broad scales not typically available at the park level, and (iv) assistance to parks in interpreting results.

NPScape products have been developed using a conceptual framework that links measurable attributes of landscapes to natural resources within parks. The conceptual framework illustrates connections among key attributes of the greater park environment and relates NPScape products to the evaluation of landscape condition and the context of parks. At its core, the NPScape framework is designed to address questions related to resource conservation vulnerability and opportunity. These dynamics are shaped at the landscape scale by three major factors: (i) natural systems, (ii) human drivers, and (iii) conservation context. Consider by way of example a focal resource like the giant sequoia (*Sequoiadendron giganteum*). Within the park, giant sequoia is capable of persisting in part because of the ecological attributes of the larger natural system within which it exists (e.g., overall amount of suitable habitat, integrity and connectedness of the habitat). However, the actual ability of the natural system to maintain viable populations of giant sequoia must be further interpreted in the context of human-mediated drivers of landscape change (e.g., population, housing, roads, and other land cover conversion). Precisely how these drivers interact with the attributes of the natural system to impact conservation vulnerability and opportunity of giant sequoia depends further on the stewardship of all management units within the surrounding natural system (e.g., landowner, level of protection, spatial context of other lands suitable for conservation). NPScape quantifies these critical landscape elements and provides them along with analysis and interpretation to parks in an effort to assist management decisions aimed at protecting natural resources like giant sequoia.

NPScape indicators for inclusion in this report were selected after careful consideration of their ecological relevance to Sequoia and Kings Canyon National Parks (Table 4). In addition, we considered metrics with respect to the general appropriateness of the spatial, temporal, and thematic resolution of the available source data available (see below). In the case of human drivers, for example, housing density in 1970 and 2010 were selected as focal indicators because – depending on proximity to a protected area like SEKI – humans and associated domesticated animals can have profound direct and indirect effects on the distribution, abundance, and population viability of native species (McDonnell and Hahs 2008). Road density and roadless area were similarly selected because traffic associated with roads is known to negatively impact many native species through roadkill, road-avoidance, and human access (Forman & Alexander 1998). A disadvantage of roads is that they are inherently difficult to map and monitor consistently over time, but road traffic is often highly correlated with local population size (National Park Service 2009). Total population by county was selected as a third indicator for monitoring local human impacts.

Table 4. NPScape landscape dynamics measures used in the SEKI NRCA

Category	Measure	Data Source[a]	Years	Spatial Resolution	SOP
Population	Total & Density by County	US Census Bureau	1790-2030, by decade	County	NPS 2010a
	Total & Density by Census block	US Census Bureau	1990, 2000	Census block groups	
Housing	Density	SERGoM	1970-2100	100 meter cells	NPS 2010b
Roads	Road Density: Weighted All roads Major roads	ESRI	2005	Varies	NPS 2011b
	Distance from Roads: All roads Major roads	ESRI	2005	Varies	
	Area without Roads, > 500 meters from: All roads Major roads	ESRI	2005	Varies	
Land cover	Percent Natural vs. Converted	NLCD	1992, 2001, 2006	30 meter cells	NPS 2010c
	Change in Natural vs. Converted	NLCD	1992, 2001, 2006	30 meter cells	
	Area / Category	NLCD	2001, 2006	30 meter cells	
	Percent Impervious	NLCD	2001, 2006	30 meter cells	
Pattern	Grassland Morphology, Patch Size, and Area Density	NLCD	2001	30 meter cells	NPS 2010d, NPS 2011c
	Forest Morphology, Patch Size, and Area Density	NLCD	2001	30 meter cells	
Conservation Status	Area Protected	PAD-US	Varies	Varies	NPS 2011d
	Ownership Area / Category	PAD-US	Varies	Varies	

Lastly, formally designated protected areas and land ownership were chosen as landscape indicators for conservation context. While no single percentage of protected area can be used to ensure protection or maintenance of biodiversity (Lindenmayer & Franklin 2002, Groves 2003, Svancara 2005), area and patch size distributions of protected areas (i.e., lands that receive permanent protection from land cover conversion and are mandated to maintain at least a primarily natural state) provide insights into whether and how species traverse the landscape through a network of formally protected natural habitats. Additionally, as evident by local planning partnerships like the Southern Sierra Partnership (see below), knowledge of surrounding land ownership is critical to coordinated resource conservation.

Data sources are considered separate from the indicators because – while the indicators are considered fundamental to all past, present, and future landscape dynamics monitoring – the sources of information used to quantify the indicators can, and hopefully will, improve over time. All sources of NPScape data considered here are summarized in Table 4.

Several important details of NPScape data merit explicit mention in this report:

- Housing density: The housing density classes follow from Theobald (2005) and the non-uniform ranges are deigned to capture dynamics of low-density housing not typically considered in non-ecological studies. Estimates of housing density originate from a data-driven model, the spatially explicit regional growth model (SERGoM), which is what permits future projections to be made for the 21^{st} Century.

- Road density and roadless area: Road data originate from ESRI (Environmental Systems Research Institute 2010). Major roads include all highways and interstates. Weighted road density is estimated by multiplying interstate lengths by a factor of 5 and highway lengths by a factor of 3; these weights are designed to capture the effects of variable traffic volume by major road type.

- Total population: While historical data originate from the US Census Bureau, the intermediate source used by NPScape was Waisanen & Bliss (2002).

- Protected areas and land ownership: In the Protected Areas Database of the US (PAD-US, Gap Analysis Program 2011), protected areas for the NPScape indicator were formally defined as areas with a GAP status code of 1 or 2; this includes most national park units and all wilderness, but excludes other areas that are not mandated to maintain at least a primarily natural state (e.g., many US Forest Service and Bureau of Land Management lands).

Socio-Economic Atlas

The socioeconomic atlas is a National Park Service series that produced a series of 18 atlases for regions surrounding national parks. These atlases are posted on the NPS Social Science Program website at http://www.nature.nps.gov/socialscience/archive.cfm#SocioAtlas. The California atlas for SEKI provides details by county on general population, economy, social and cultural characteristics, recreation, tourism, government, and land use. Because all maps are presented at the county-level, and because source data are not made available for general use, socioeconomic atlas information was not used explicitly in this chapter. Most of the relevant socioeconomic indicators considered in the atlas (e.g., population, developed land cover by use category) were instead quantified using indicators and data furnished by NPScape. However, the report was used as reference and comparative purposes for similar elements that are covered here.

NatureServe Contributions

NatureServe is a research non-profit originating from The Nature Conservancy. The group has been actively developing a landscape mapping program that is consistent with the National Vegetation Classification System (http://www.fgdc.gov/standards/projects/FGDC-standards-projects/vegetation). They provided their vegetation map of the PACE region for evaluation with other maps.

Southern Sierra Partnership Report

Ecosystem services were detailed as part of a report by the Southern Sierra Partnership (SSP), a consortium of non-profit organizations with technical leads The Nature Conservancy, with Conservation Biology Institute, Audubon California, Sequoia Riverlands Trust, Sierra Business Council, and Tejon Ranch Conservancy. The report, 'Climate-adapted conservation plan for the Southern Sierra Nevada and Tehachapi Mountains' was published in 2010, consisting of 228 pages (SSP 2010). The report covers a wide range of topics. For inclusion here we used two ecosystem services that they quantified, for which their GIS data extended beyond the study area of their report to cover the PACE boundary area used in this report. We used their measures for Standing Carbon, described as MegaGrams/km^2 and Water Yield, described in acre/feet.

SSP National Biomass Carbon

The Standing Carbon is described in the GIS file metadata (SSP 2010) as a portrayal of the National Biomass Carbon dataset (NBCD 2000; available at Woods Hole Research Center; http://www.whrc.org/mapping/nbcd/index.html), with additional data supplied by the California Department of Fire and Resource Assessment Program (FRAP) that produced a study titled "Biomass Potentials from California Forest and Shrublands Including Fuel Reduction Potentials to Lessen Wildfire Threat." For the California Energy Commission's PIER program (Sethi & Simons 2005). The map is compiled at 100 m. The NBCD report details biomass for live trees, which the SSP group multiplied by 0.5, representing an assumption that 50% of biomass is carbon, a general average for California. The Sethi and Simons (2005) data were used for areas that the NBCD data did not cover. The metadata states that errors may be likely, understandable since this represents one of the first efforts to quantify standing carbon in California.

SSP Water Yield Map

The water yield map is also derived from data used in the SSP report. Water yield is the volume of water that does not evapotranspire from an ecosystem, and therefore is potentially available for use. Water yield can take the form of storm runoff, baseflow or deep groundwater. In this model, yield is a function of average annual precipitation, annual reference evapotranspiration, soil depth, plant available water content and plant root depth. Values are average annual yield (acre feet) of water. These data were originally developed by The Nature Conservancy, California for use in The Nature Capitol project.

Other data sources used

Digital versions of the US Geological Survey elevation and geology were used. Two modeled versions of landscape connectivity were used, a federal model by David Theobald (originally a

PALMs project) and a California State-sponsored model. The Sequoia and Kings Canyon vegetation map is also presented.

Reference conditions

For environmental climate variables we are able to document change from a 30-year mean of 1910-1940, and how temperature, precipitation have changed using a contemporary mean from 1970-2000. Similarly, we can compare trends for derived climate-related values such as climatic water deficit, soil moisture and runoff. The 30-year means of these climate variables were previously calculated by Thorne (in prep) for a project for the California Energy Commission. The reasoning to use 30 years is to average in cycles such as the Pacific Decadal Oscillation, and El Niños or La Niñas so that trend in baseline conditions can be measured. Interpolated historic climate data at monthly time steps is available back to at least 1900 from the PRISM group, but the earliest records are derived from only a few weather stations. Therefore the Thorne group elected to not include the 1900-1910 data in the earliest spatial climate time series.

Static physical variables, attributes such as elevation, have not changed perceptibly over the time period considered in this study. Hence change is not assessed and current attributes are treated as baseline values.

For human impact variables, we make the assumption that there were no human constructs on the landscape that greatly affected the focal elements of the study from pre-settlement times. Certainly the landscape was used by Native Americans, but impacts from their patterns of use are not fully known or even partially quantified. Post-settlement impacts start from a presumed zero impacts, meaning that current levels of fragmentation, population density, etc. represent deviations from the baseline. In some cases, such as for housing density, we have data from two time periods, permitting an evaluation of trend, even if not from pre-settlement conditions. Dates of such data are identified when they are presented.

For the conservation status elements, many of the maps and data presented represent first-generation attempts to document status at a landscape scale, and as such represent a reference condition. We acknowledge that these attributes do not represent pre-settlement reference conditions as they are already be in the process of change. We also acknowledge that the variables themselves may be better modeled with additional data. For example estimates of climatic water deficit are constrained by the quality of available data.

Spatial and temporal analyses

1. Physical Geography

This section contains summary information on abiotic factors, natural ecosystems, climate, and ecosystem service data which were compiled and are shown here to help set a regional context and illustrate, for each element, the contributions of the Sequoia Kings Canyon National Parks to the PACE region.

Elevation

SEKI NP contains the highest point in the lower 48 states in Mt. Whitney, standing 4421 m, meaning that SEKI contains within its boundaries one of the largest elevational gradients in California. Relative to the PACE area, SEKI contains a disproportionately large fraction of high elevation habitat. Just over half of SEKI lies above 3000 m, compared to just 11% of the PACE region (Figures 1 & 2). Another way of stating this is that SEKI represents 7.75% of the PACE area but contains 36% of land above 3000 m in elevation and 51% of land above 3500 m (Table 5). Further, SEKI NP holds less than 1% of the PACE region's lands below 1500 m.

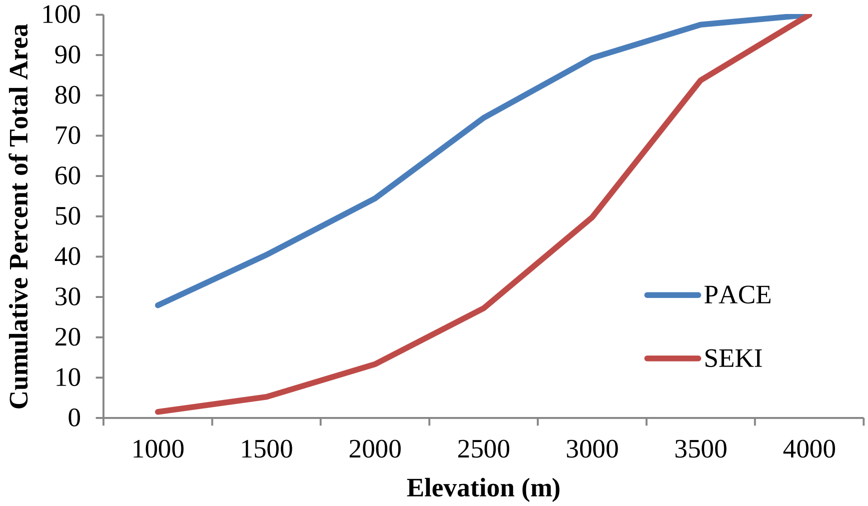


Figure 2. The cumulative percent of land in different elevation categories demonstrating the relative higher elevation of SEKI compared to the PACE region.

Table 5. Comparative areas in SEKI and the PACE region by elevation zone.

Elevation	PACE		SEKI NP	
Classes (m)	Total Area (km^2)	Percent	Total Area (km^2)	Percent
≥ 3,500	1,111.6	2.5	569.6	16.3
3,000 – 3,500	3,735.4	8.3	1,185.6	34.0
2,500 – 3,000	6,701.4	14.9	787.3	22.6
2,000 – 2,500	9,009.6	20.0	483.5	13.8
1,500 – 2,000	6,280.1	13.9	283.7	8.1
1,000 – 1,500	5,641.6	12.5	130.9	3.7
0 – 1,000	12,581.6	27.9	50.4	1.4

Geology

The geology of the Sierra Nevada is dominated by granite, comprising 58% of the PACE region, and 87% of SEKI NP (Figure 3; Table 6). Three other geologic types make up the remaining majority of the Park: glacial till alluvium (2.8%), Metamorphics (3.7%) and Metavolcanics (3.8%). By contrast in the PACE region, following granite, the geologic landscape is dominated by Volcanics (9.7%), Sandstone (8.7%) and Alluvium (5.9%).

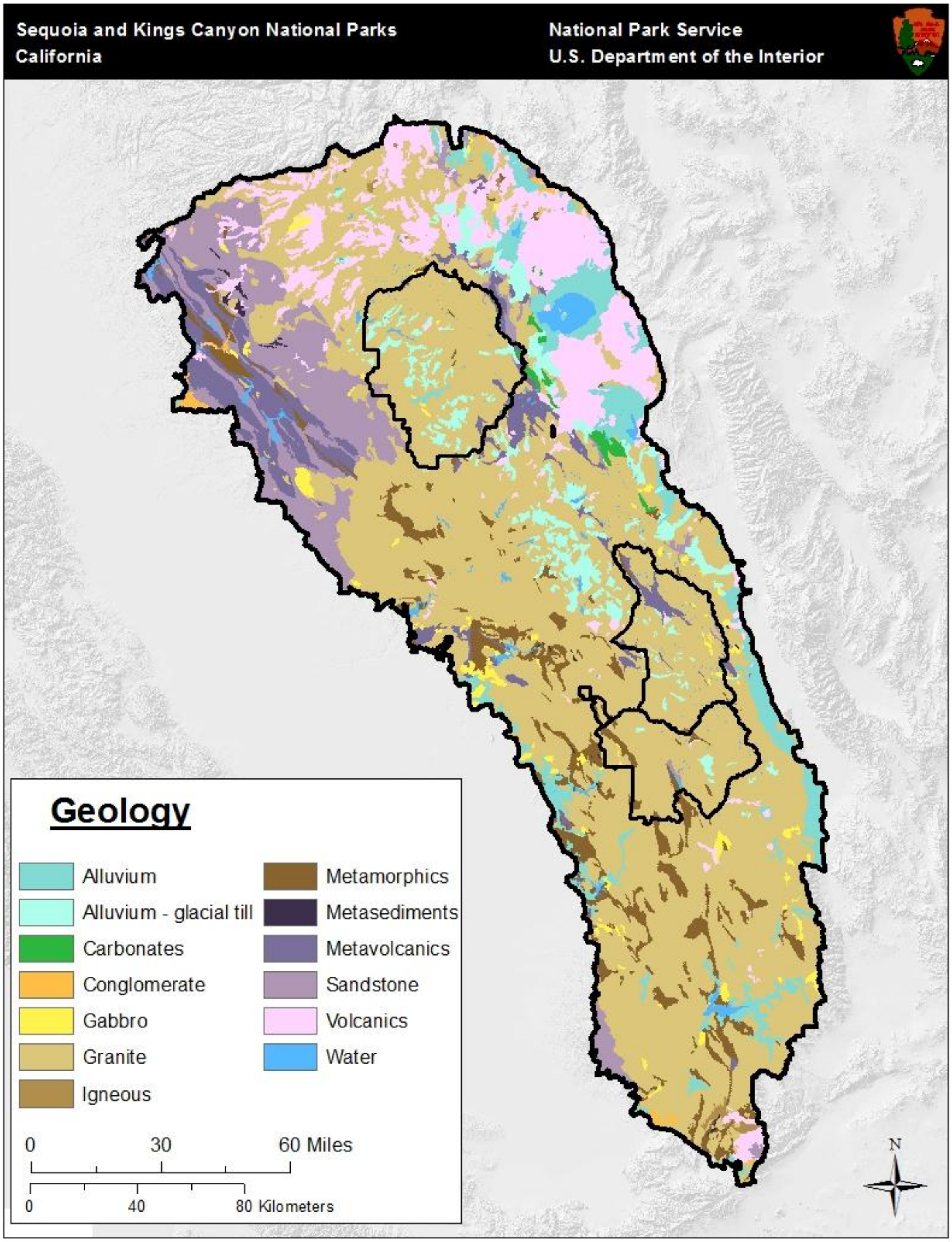


Figure 3. The Geology of the Pace region with SEKI NP included. The many small lakes in the high Sierra Nevada are not visible due to the scale of the image.

Table 6. The extent of different geologic types in the PACE and SEKI NP regions.

Geology	PACE		SEKI NP	
Classes	Total Area (km^2)	Percent	Total Area (km^2)	Percent
Alluvium	2,653.5	5.9		
Alluvium – glacial till	1,729.6	3.8	99.6	2.8
Carbonates	168.8	0.4		
Conglomerate	220.1	0.5		
Gabbro	571.5	1.3	26.5	0.8
Granite	26,237.7	57.9	3,041.0	86.8
Igneous	94.7	0.2		
Metamorphics	2,309.9	5.1	130.1	3.7
Metasediments	70.9	0.2	1.7	0
Metavolcanics	2,246.1	5	134.7	3.8
Sandstone	3,955.2	8.7	24.4	0.7
Volcanics	4,410.2	9.7	8	0.2
Water	626.3	1.4	36.5	1.0

Yearly Minimum Temperature

Yearly Minimum temperature (Tmin) is a measure of the average of nighttime low temperatures. We combined 30 years' nighttime lows to get an average centered on 1925, and another centered on 1985. These are represented in Figures 4 & 5 below. We then took the difference between the two maps to portray how Tmin has changed over the past 60 years (Figure 6; Tables 7 & 8). The PACE region contains areas that have warmed as well as areas that have cooled. The pattern is not simple. In general, however, the lower, warmer areas warmed more and the areas that experienced lower nighttime minimum temperatures were at higher elevation (Figure 6). The area in SEKI that appears to have warmed the most, by about 1.3°C, lies in the western coniferous belt. A large section of the eastern Sierra Nevada located between SEKI NP and Yosemite NP to the north shows cooling of about 1°C. It is important to bear in mind that these results are from a downscaled PRISM model of climate station data. With few actual climate stations in the region, the patterns generally reflect changes at those few stations, interpolated and fit to environmental drivers of temperature (e.g., elevation).

Data from two general circulation models (GCMs) were used to compare projected future climate conditions to observed current climate conditions. As with the historic data, 30 years of projected nighttime lows were combined to get an average centered on 2085. The change in Tmin projected by the GFDL and PCM GCMs under the IPCC A2 scenario is represented in Figures 7 & 8. The future climatologies used here and other places in the report were developed and downscaled as part of the California Energy Commission's PIER program initiative to assess vulnerability in different sectors, described in the introduction of this report. We selected the A2 scenario from IPCC because the other scenario, B1, that was produced for PIER has already been surpassed, in terms of the concentration levels of greenhouse gases in the atmosphere. The model outputs from that project used here are at a 270 m grid scale.

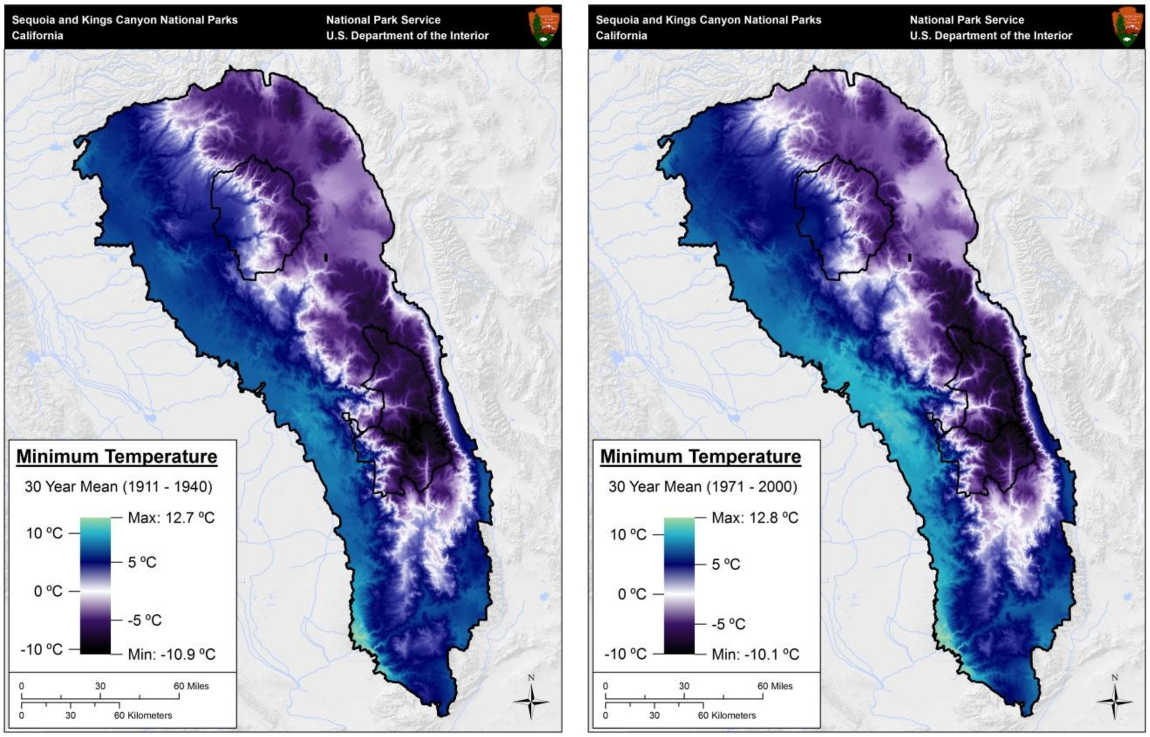


Figure 4 & 5. Annual minimum temperatures in degrees Celsius from a 30-year mean centered of annual values 1911-1940, and from 1971-2000.

Table 7. The extent of annual minimum temperatures by quartile of the range on values found within the PACE and SEKI boundaries historically, in current time, and the difference between them.

Minimum Temperature				
1911 – 1940 by Quartile	**PACE**		**SEKI NP**	
Classes (degree C)	**Area (km^2)**	**Percent**	**Area (km^2)**	**Percent**
-10.9 – -4.9	5,201.9	11.5	2,248.5	64.1
-4.9 – 0.9	15,029.4	33.2	948.7	27.1
0.9 – 6.8	15,200.7	33.6	233.9	6.7
6.8 – 12.7	9,107.5	20.1	37.1	1.1
Water (Lakes and Rivers)	663.5	1.5	38.0	1.1
No Data	0	0	0	0
1971 – 2000 by Quartile	**PACE**		**SEKI NP**	
Classes (degree C)	**Area (km^2)**	**Percent**	**Area (km^2)**	**Percent**
-10.9 – -4.9	4,001.2	8.9	1,989.7	56.7
-4.9 – 0.9	15,470.3	34.2	1,151.5	32.8
0.9 – 6.8	14,556.7	32.2	277.9	7.9
6.8 – 12.7	10,511.3	23.3	49.2	1.4
Water	663.5	1.5	38.0	1.1
No Data	0	0	0	0
Difference (cur ave - his ave)	**PACE**		**SEKI NP**	
Classes (degree C)	**Area (km^2)**	**Percent**	**Area (km^2)**	**Percent**
-10.9 – -4.9	-1,200.7	-2.7	-258.8	-7.4
-4.9 – 0.9	440.9	1.0	202.7	5.8
0.9 – 6.8	-644.0	-1.4	44.0	1.3
6.8 – 12.7	1,403.8	3.1	12.1	0.3
Water	0	0	0	0
No Data	0	0	0	0

Table 8. The extent of annual minimum temperatures by elevation band of the range on values found within the PACE and SEKI boundaries historically, in current time, and the difference between them.

Minimum Temperature				
1911 – 1940 by Elevation	**PACE**		**SEKI NP**	
Elevation Classes (m)	**Average**	**Standard Deviation**	**Average**	**Standard Deviation**
≥ 3,500	-7.7	1.3	-8.4	1.3
3,000 – 3,500	-5.8	1.5	-7.2	1.1
2,500 – 3,000	-3.6	1.8	-5.3	1.0
2,000 – 2,500	-1.1	2.6	-2.9	1.3
1,500 – 2,000	2.3	2.5	0.1	1.7
1,000 – 1,500	4.7	1.4	3.8	1.8
0 – 1,000	7.3	1.2	7.4	0.8
1971 – 2000 by Elevation	**PACE**		**SEKI NP**	
Elevation Classes (m)	**Average**	**Standard Deviation**	**Average**	**Standard Deviation**
≥ 3,500	-8.1	1.0	-8.6	0.7
3,000 – 3,500	-5.7	1.6	-7.0	0.9
2,500 – 3,000	-2.8	1.7	-4.6	1.0
2,000 – 2,500	-0.4	2.4	-1.9	1.3
1,500 – 2,000	2.8	2.5	1.0	1.6
1,000 – 1,500	5.3	1.5	4.4	1.7
0 – 1,000	8.1	1.6	7.9	1.0
Difference (cur ave - his ave)	**PACE**		**SEKI NP**	
Elevation Classes (m)	**Average**	**Standard Deviation**	**Average**	**Standard Deviation**
≥ 3,500	-0.4	0.9	-0.2	1.0
3,000 – 3,500	0.2	0.9	0.3	0.9
2,500 – 3,000	0.8	0.7	0.8	0.5
2,000 – 2,500	0.8	0.6	1.0	0.4
1,500 – 2,000	0.6	0.7	0.9	0.5
1,000 – 1,500	0.6	0.5	0.6	0.5
0 – 1,000	0.7	0.7	0.5	0.4

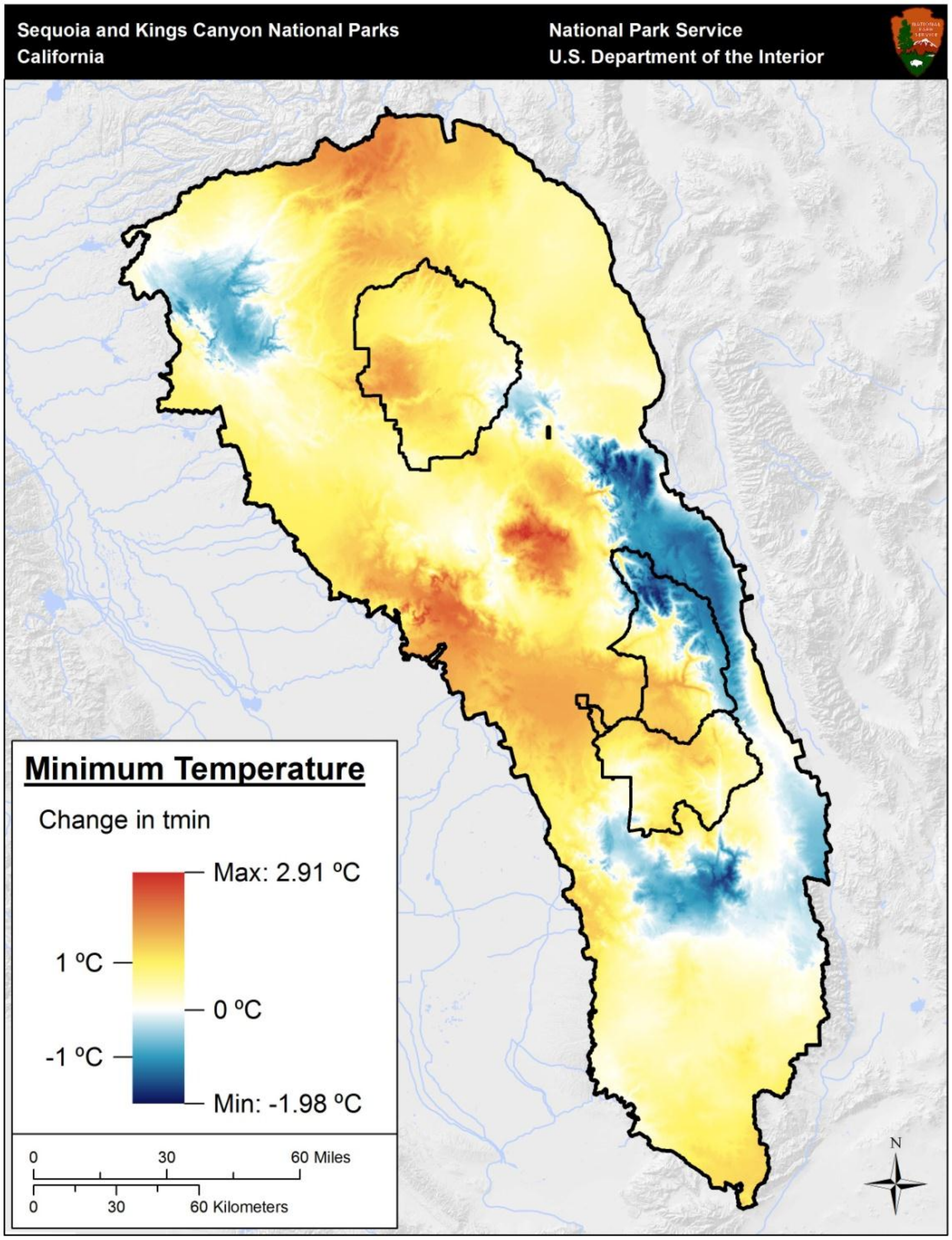
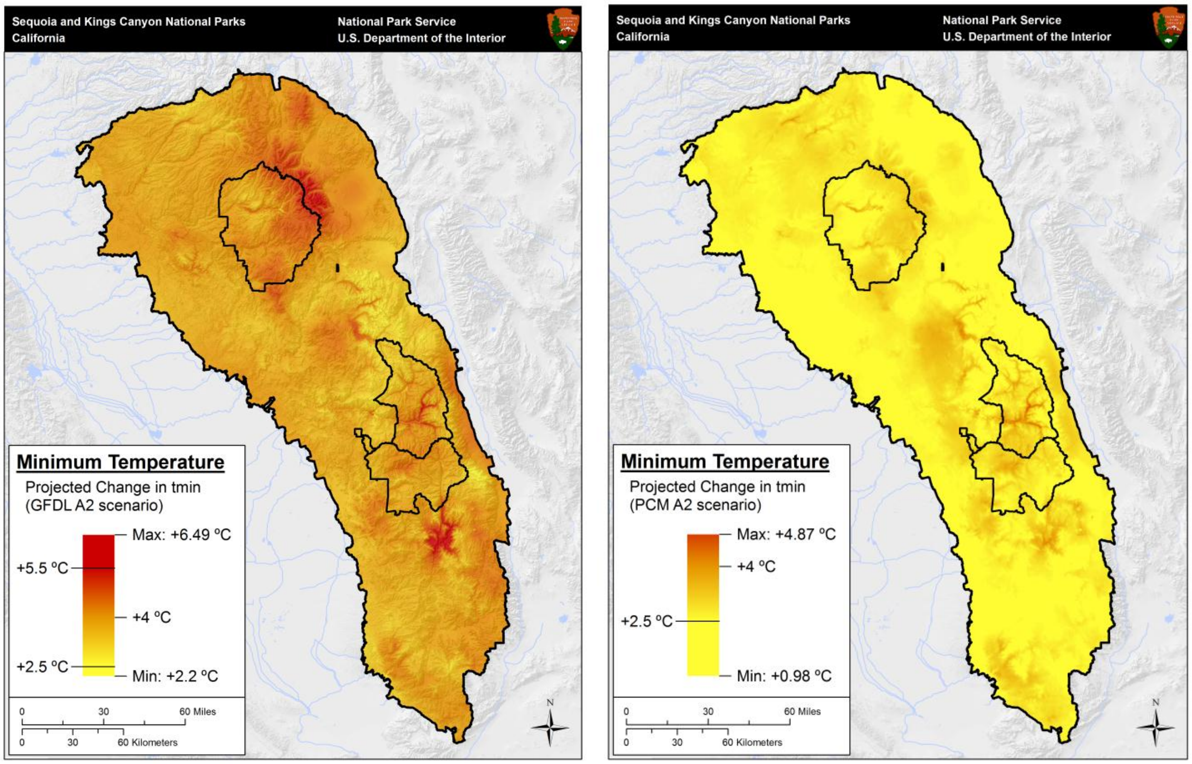


Figure 6. Change in annual minimum temperatures in degrees Celsius between a 30-year mean centered of annual values 1911-1940, and from 1971-2000.

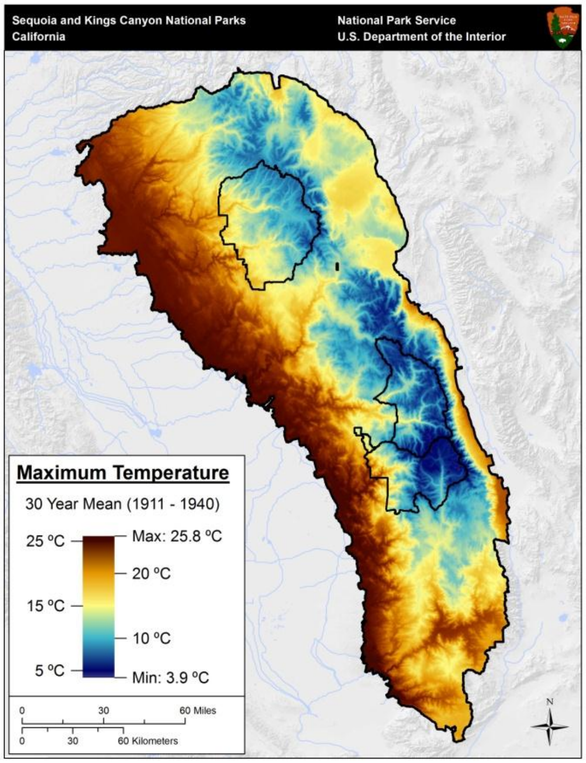


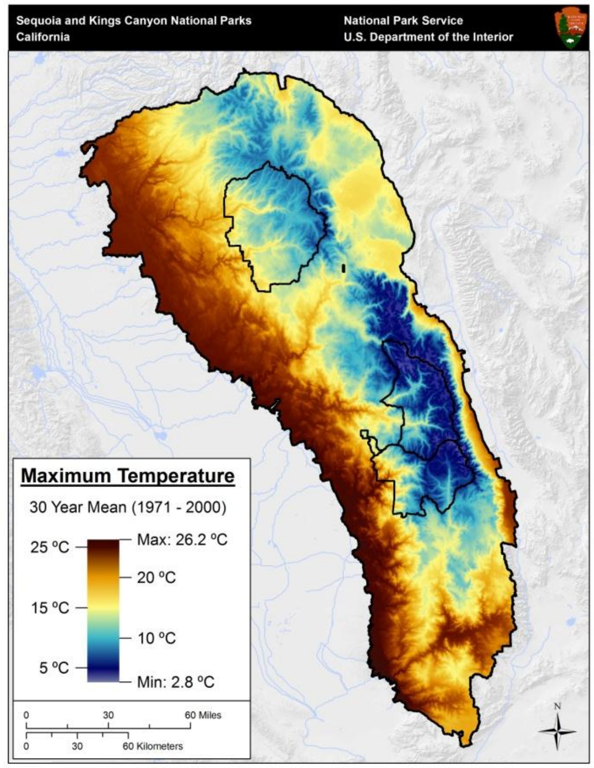
Figures 7 & 8. Change in annual minimum temperatures in degrees Celsius between a 30-year mean centered of annual values 1971-2000, and projected change under two future GCMs (GFDL and PCM) under the A2 scenario for 2071-2100.

Yearly Maximum Temperatures

Yearly Maximum temperature (Tmax) is a measure of the average of daytime high temperatures. We combined 30 years' daytime highs to get an average centered on 1925, and another centered on 1985. These are represented in Figures 9 & 10 below. We then took the difference between the two maps to portray how Tmax has changed over the past 60 years (Figure 11; Tables 9 & 10). Daytime highs appear more stable than nighttime lows, as evidenced by the areas in white, representing change of less than 10% towards either warming or cooling, relative to the current 30-year means for Tmax and Tmin. Tmax temperatures in Kings Canyon NP appear to have decreased, and the cooling shown in Tmin, on the east side of the Sierra Nevada crest, is also seen in the Tmax signal (Figures 11).

Projected changes in Tmax were determined in the same manner as was done with Tmin. The change in Tmax projected by the GFDL and PCM GCMs under the IPCC A2 scenario is represented in Figures 12 & 13.





Figures 9 & 10. Annual maximum temperatures in degrees Celsius from a 30-year mean centered of annual values 1911-1940, and from 1971-2000.

Table 9. The extent of annual maximum temperatures by quartile of the range on values found within the PACE and SEKI boundaries historically, in current time, and the difference between them.

Maximum Temperature				
1911 – 1940 by Quartile	**PACE**		**SEKI NP**	
Classes (degree C)	**Area (km^2)**	**Percent**	**Area (km^2)**	**Percent**
2.8 – 8.6	3,840.8	8.5	1,827.8	52.1
8.6 – 14.5	14,309.4	31.7	1,330.6	37.9
14.5 – 20.4	12,888.1	28.5	270.9	7.7
20.4 – 26.2	13,501.3	29.9	38.9	1.1
Water	663.5	1.5	38.0	1.1
No Data	0	0	0	0
1971 – 2000 by Quartile	**PACE**		**SEKI NP**	
Classes (degree C)	**Area (km^2)**	**Percent**	**Area (km^2)**	**Percent**
2.8 – 8.6	4,440.4	9.8	2,066.5	58.9
8.6 – 14.5	14,416.4	31.9	1,107.9	31.6
14.5 – 20.4	12,271.2	27.1	249.4	7.1
20.4 – 26.2	13,411.6	29.7	44.5	1.3
Water	663.5	1.5	38.0	1.1
No Data	0	0	0	0
Difference (cur ave - his ave)	**PACE**		**SEKI NP**	
Classes (degree C)	**Area (km^2)**	**Percent**	**Area (km^2)**	**Percent**
2.8 – 8.6	599.6	1.3	238.7	6.8
8.6 – 14.5	107.0	0.2	-222.7	-6.4
14.5 – 20.4	-616.9	-1.4	-21.5	-0.6
20.4 – 26.2	-89.7	-0.2	5.5	0.2
Water	0	0	0	0
No Data	0	0	0	0

Table 10. The extent of annual maximum temperatures by elevation band of the range on values found within the PACE and SEKI boundaries historically, in current time, and the difference between them.

Maximum Temperature				
1911 – 1940 by Elevation	**PACE**		**SEKI NP**	
Elevation Classes (m)	**Average**	**Standard Deviation**	**Average**	**Standard Deviation**
≥ 3,500	6.2	1.0	5.8	1.0
3,000 – 3,500	8.1	1.1	7.2	1.0
2,500 – 3,000	10.6	1.4	9.3	1.0
2,000 – 2,500	13.7	1.6	11.8	1.0
1,500 – 2,000	16.6	1.6	14.4	1.1
1,000 – 1,500	19.4	1.3	17.5	1.4
0 – 1,000	23.1	1.3	21.1	1.0
1971 – 2000 by Elevation	**PACE**		**SEKI NP**	
Elevation Classes (m)	**Average**	**Standard Deviation**	**Average**	**Standard Deviation**
≥ 3,500	4.3	1.2	4.0	0.8
3,000 – 3,500	7.4	1.7	6.1	1.0
2,500 – 3,000	10.5	1.5	8.8	1.0
2,000 – 2,500	13.6	1.7	11.5	1.1
1,500 – 2,000	16.3	1.9	14.2	1.3
1,000 – 1,500	19.2	1.7	17.6	1.5
0 – 1,000	22.9	1.4	21.4	1.1
Difference (cur ave - his ave)	**PACE**		**SEKI NP**	
Elevation Classes (m)	**Average**	**Standard Deviation**	**Average**	**Standard Deviation**
≥ 3,500	-1.9	1.2	-1.8	1.2
3,000 – 3,500	-0.8	1.2	-1.1	1.1
2,500 – 3,000	-0.1	0.7	-0.5	0.7
2,000 – 2,500	-0.1	0.6	-0.3	0.4
1,500 – 2,000	-0.3	0.8	-0.1	0.4
1,000 – 1,500	-0.2	0.9	0.1	0.2
0 – 1,000	-0.2	0.6	0.3	0.1

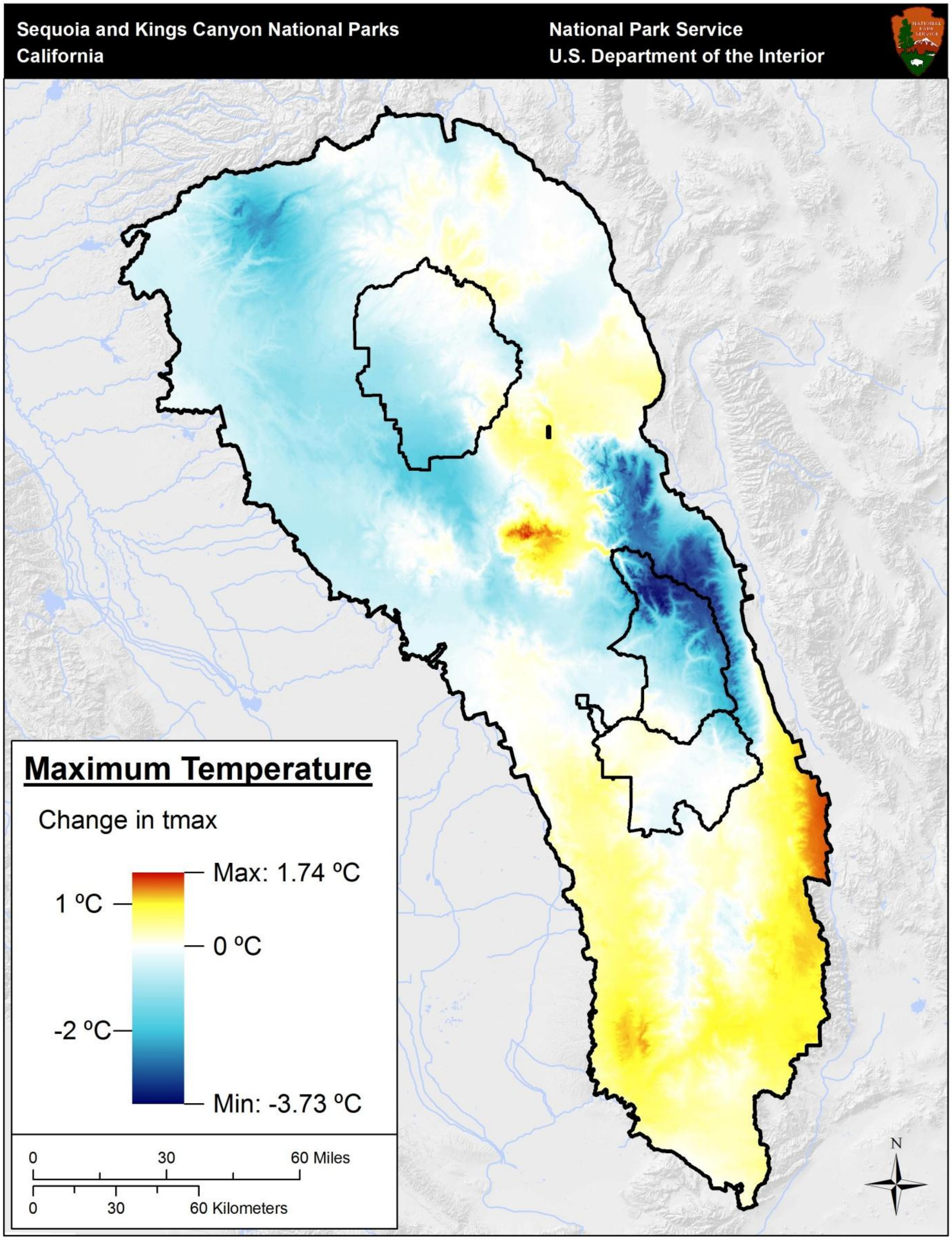
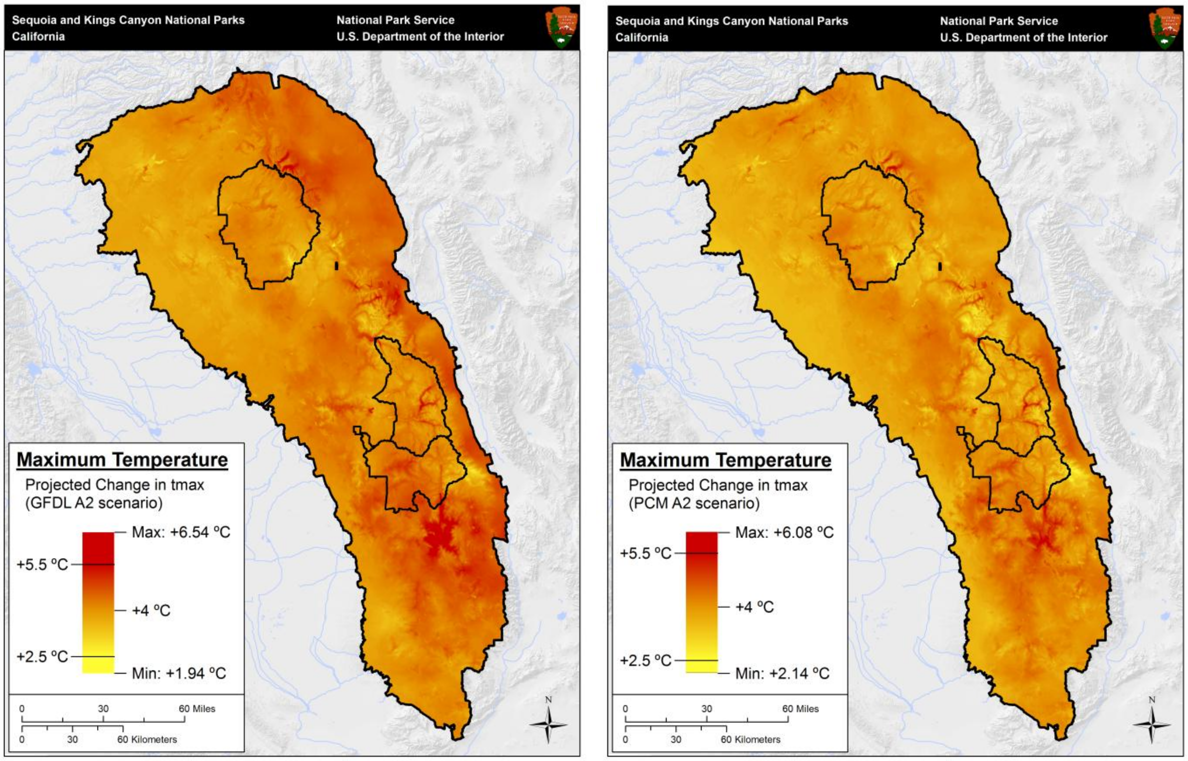


Figure 11. Change in annual maximum temperatures in degrees Celsius between a 30-year mean centered of annual values 1911-1940, and from 1971-2000.



Figures 12 & 13. Change in annual maximum temperatures in degrees Celsius between a 30-year mean centered of annual values 1971-2000, and projected change under two future GCMs (GFDL and PCM) under the A2 scenario for 2071-2100.

Yearly Melt and Freeze Cycles

The yearly snowmelt and freezing cycle can be portrayed spatially through the use of monthly minimum nighttime temperatures. Where monthly mean nighttime low temperatures transition from below to above 0°C, these areas can be assumed to either no longer hold a snow pack, or that snowmelt in those locations will begin to increase. Therefore the spatial pattern of where winter conditions have extended to by month can be mapped, as can the springtime melt out. We show the progression of winter (Figures 14 & 15) and spring (Figures 18 & 19) in side by side graphics using the same 30-year means 1911-1940, and 1971-2000. Future conditions, as projected by the GFDL and PCM GCMs under the IPCC A2 scenario, are shown for winter freezeline progression (Figures 16 & 17) and spring melt line progression (Figures 20 & 21).

There are more marked changes in the PACE region than in the Parks. Specifically, some areas that historically froze or melted in January, at the lowest elevations of the freeze line on the west side of the Sierra Nevada, no longer freeze at all. Since the Parks have the highest elevations in the region, these show less change. For set-up conditions where the areas freeze for the winter, the high elevations SEKI NP region used to freeze in August and September, but they are predicted to set up October or September under the future conditions, essentially adding six weeks to the end of the summer/fall season. Spring melt out in the high elevations now occurs in June and July (on average), but is projected to melt out in May and June under the future scenarios. This is the equivalent of a month-earlier melt out for the region. The changes shown at the highest elevations are repeated for different times at lower elevations throughout the PACE region.

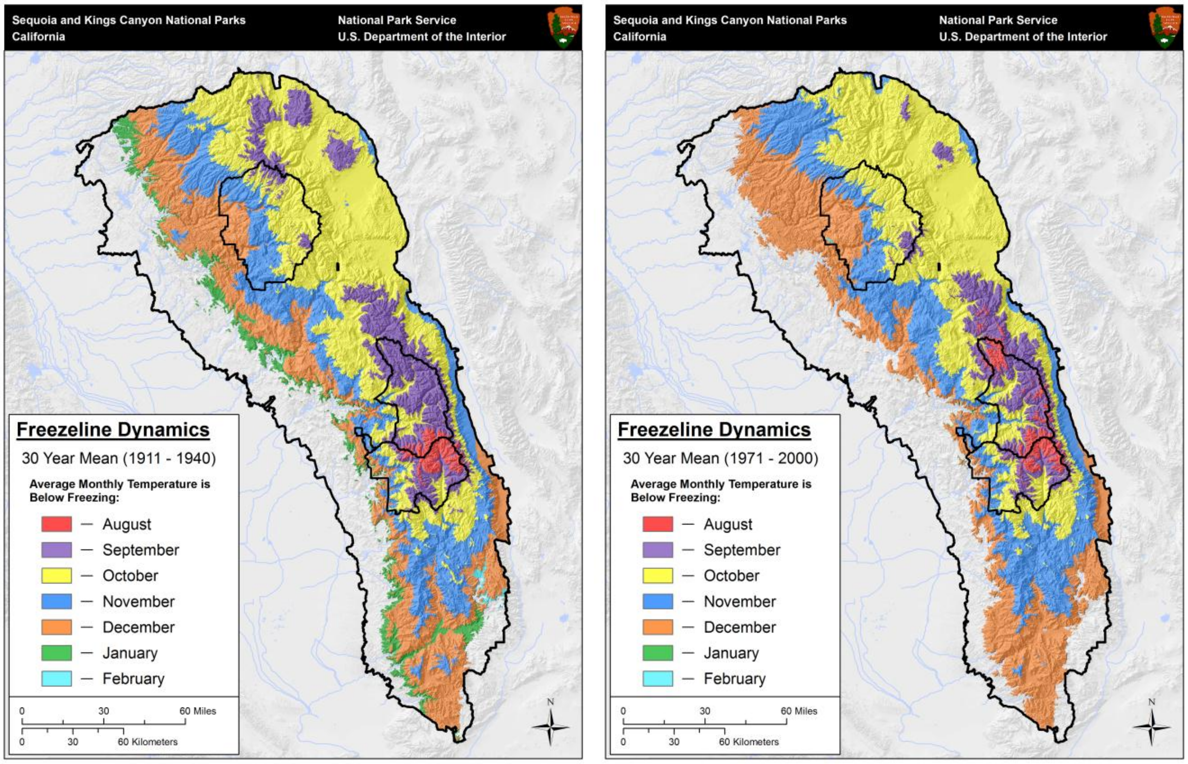
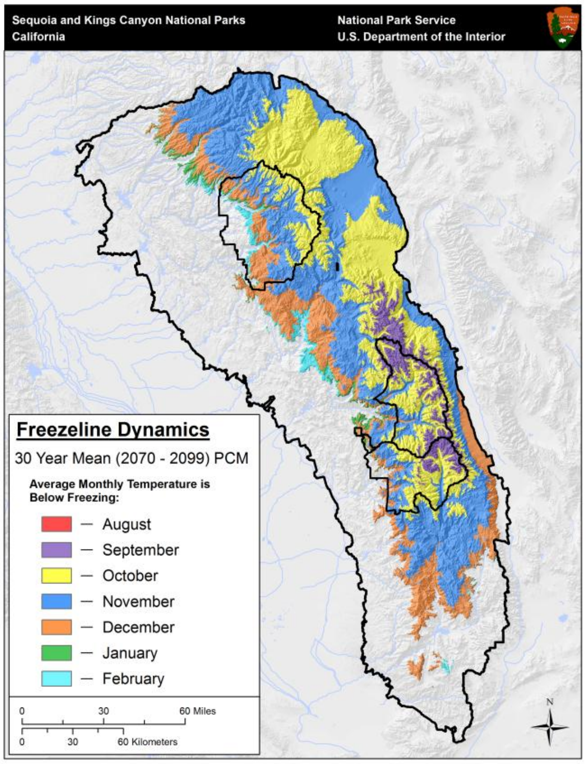


Figure 14 & 15. The temporal progression of freezing nighttime temperatures from highest elevations to lower during the freezing section of the yearly temperature cycle. Note that in the current 30-year mean, more of the high elevations of SEKI are modeled to freeze at night during August than historically. Also note some areas that are modeled to have frozen in January, at the lowest frozen elevations historically, now do not freeze over the winter period.



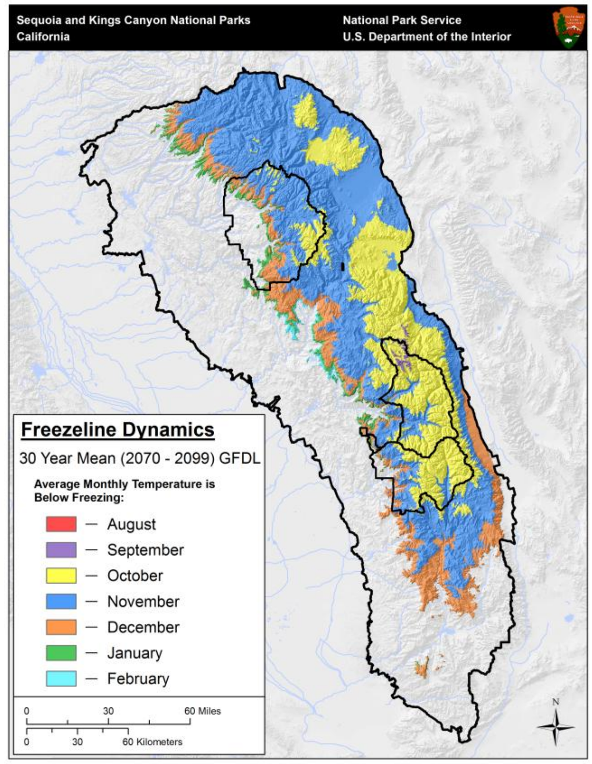
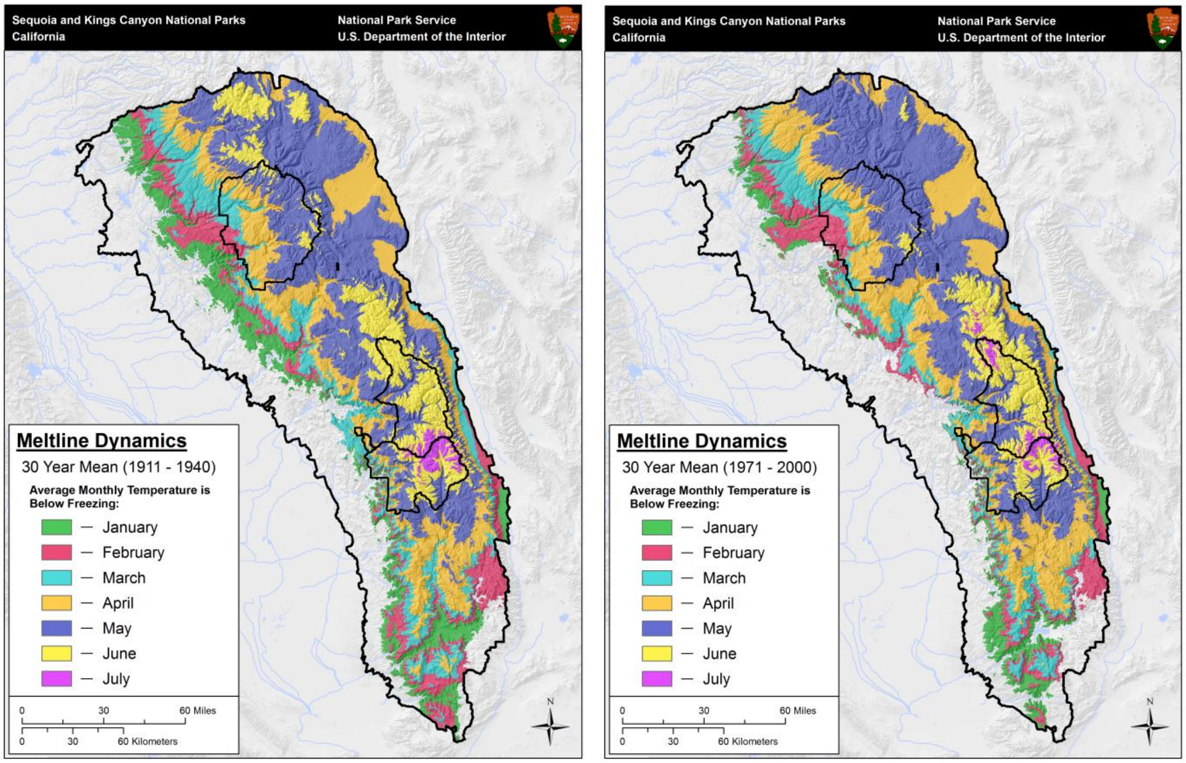
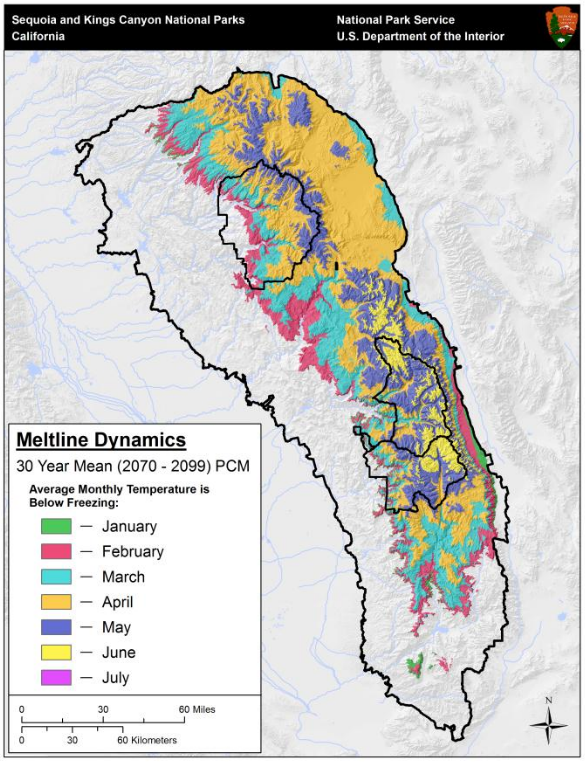
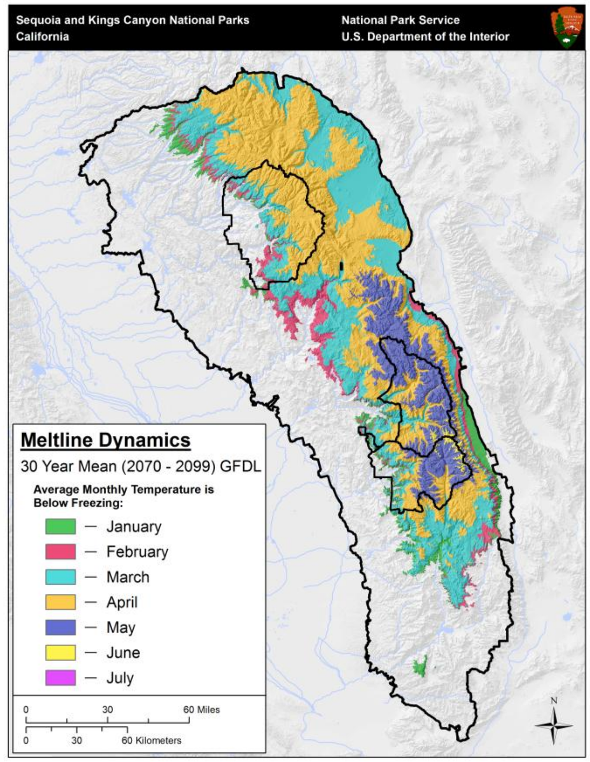


Figure 16 & 17. The temporal progression of freezing nighttime temperatures from highest elevations to lower during the freezing section of the yearly temperature cycle, as projected by the PCM and GFDL GCMs.



Figures 18 & 19. The temporal progression of melt conditions (representing spring thaw) to the PACE and SEKI regions during the springtime section of the yearly temperature cycle. Note that that the areas to the west and lower than the Parks historically recorded some springtime thaw in January, whereas in current times these areas predominantly do not freeze.

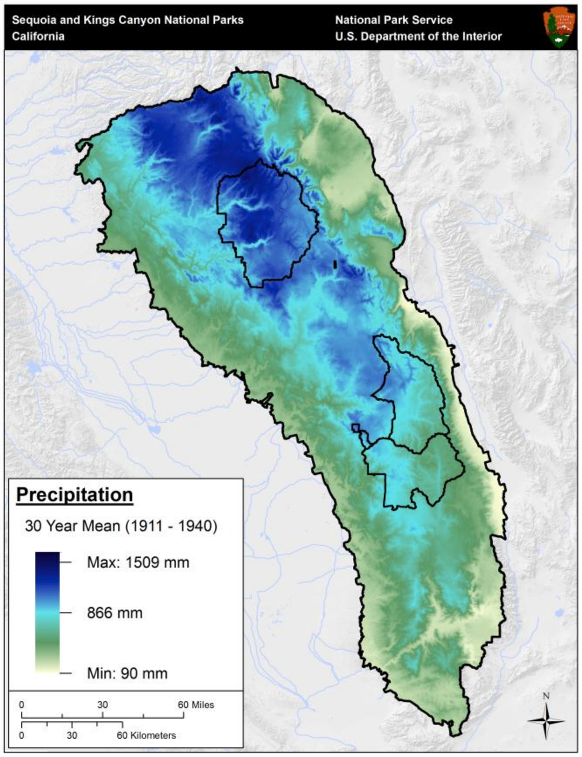




Figures 20 & 21. The temporal progression of melt conditions (representing spring thaw) to the PACE and SEKI regions during the springtime section of the yearly temperature cycle, as projected by the PCM and GFDL GCMs.

Yearly Precipitation

Yearly precipitation was calculated on the water year for California, from October 1 to September 30. Thirty-year annual precipitation means (Figures 22 & 23) were compared and change in precipitation calculated (Figure 24; Tables 11 & 12). Most of SEKI shows a slight increase in annual precipitation, while there has been a significant drying on the eastern border of Yosemite National Park, further north. The largest increase in precipitation, ~240 mm, has occurred between the two NPS units, in the center of the PACE region.



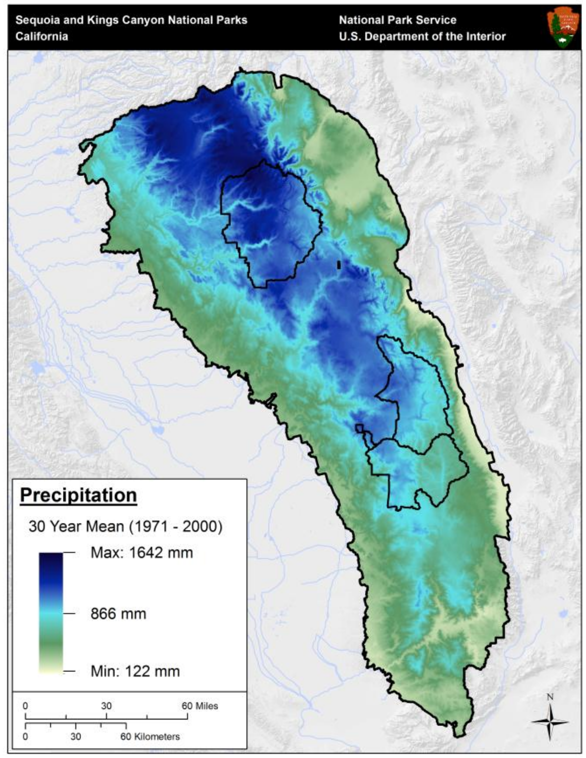


Figure 22 & 23. Annual precipitation in millimeters from a 30-year annual means 1911-1940, and from 1971-2000.

Table 11. The extent of annual precipitation (mm) by quartile of the range on values found within the PACE and SEKI boundaries historically, in current time, and the difference between them.

Precipitation				
1911 – 1940 by Quartile	**PACE**		**SEKI NP**	
Classes (mm)	**Area (km^2)**	**Percent**	**Area (km^2)**	**Percent**
90.4 – 478.3	13,145.8	29.1	4.7	0.1
478.3 – 866.1	16,514.4	36.5	2,554.2	72.8
866.1 – 1,253.9	13,269.6	29.4	909.3	25.9
1,253.9 – 1,641.8	1,609.8	3.6	0	0
Water	663.5	1.5	38	1.1
No Data	0	0	0	0
1971 – 2000 by Quartile	**PACE**		**SEKI NP**	
Classes (mm)	**Area (km^2)**	**Percent**	**Area (km^2)**	**Percent**
90.4 – 478.3	11,098.0	24.6	0	0
478.3 – 866.1	15,838.7	35.0	1,724.6	49.2
866.1 – 1,253.9	14,317.2	31.7	1,743.6	49.7
1,253.9 – 1,641.8	3,285.7	7.3	0	0
Water	663.5	1.5	38	1.1
No Data	0	0	0	0
Difference (cur ave - hist ave)	**PACE**		**SEKI NP**	
Classes (mm)	**Area (km^2)**	**Percent**	**Area (km^2)**	**Percent**
90.4 – 478.3	-2,047.8	-4.5	-4.7	-0.1
478.3 – 866.1	-675.7	-1.5	-829.6	-23.7
866.1 – 1,253.9	1,047.6	2.3	834.3	23.8
1,253.9 – 1,641.8	1,675.9	3.7	0	0
Water	0	0	0	0
No Data	0	0	0	0

Table 12. The extent of annual precipitation (mm) by elevation band of the range on values found within the PACE and SEKI boundaries historically, in current time, and the difference between them.

Precipitation				
1911 – 1940 by Elevation	**PACE**		**SEKI NP**	
Elevation Classes (m)	**Average**	**Standard Deviation**	**Average**	**Standard Deviation**
≥ 3,500	748.4	171.8	665.1	134.0
3,000 – 3,500	838.2	232.5	710.9	148.6
2,500 – 3,000	882.2	288.4	798.1	123.8
2,000 – 2,500	733.0	341.2	873.3	89.4
1,500 – 2,000	710.0	354.1	891.7	58.1
1,000 – 1,500	669.3	331.4	801.0	53.1
0 – 1,000	538.7	204.2	634.0	53.2
1971 – 2000 by Elevation	**PACE**		**SEKI NP**	
Elevation Classes (m)	**Average**	**Standard Deviation**	**Average**	**Standard Deviation**
≥ 3,500	820.3	149.4	757.7	131.4
3,000 – 3,500	896.0	221.2	803.1	144.8
2,500 – 3,000	945.8	301.5	888.6	122.1
2,000 – 2,500	798.2	364.9	961.6	87.2
1,500 – 2,000	785.5	370.1	965.2	57.9
1,000 – 1,500	733.5	344.6	858.4	58.4
0 – 1,000	589.1	213.5	685.0	51.9
Difference (cur ave - hist ave)	**PACE**		**SEKI NP**	
Elevation Classes (m)	**Average**	**Standard Deviation**	**Average**	**Standard Deviation**
≥ 3,500	71.9	48.2	92.7	33.8
3,000 – 3,500	57.7	50.6	92.2	27.8
2,500 – 3,000	63.7	52.5	90.5	24.1
2,000 – 2,500	65.2	54.0	88.3	23.5
1,500 – 2,000	75.5	38.5	73.6	19.2
1,000 – 1,500	64.2	25.9	57.4	10.5
0 – 1,000	50.4	18.8	51.0	5.2

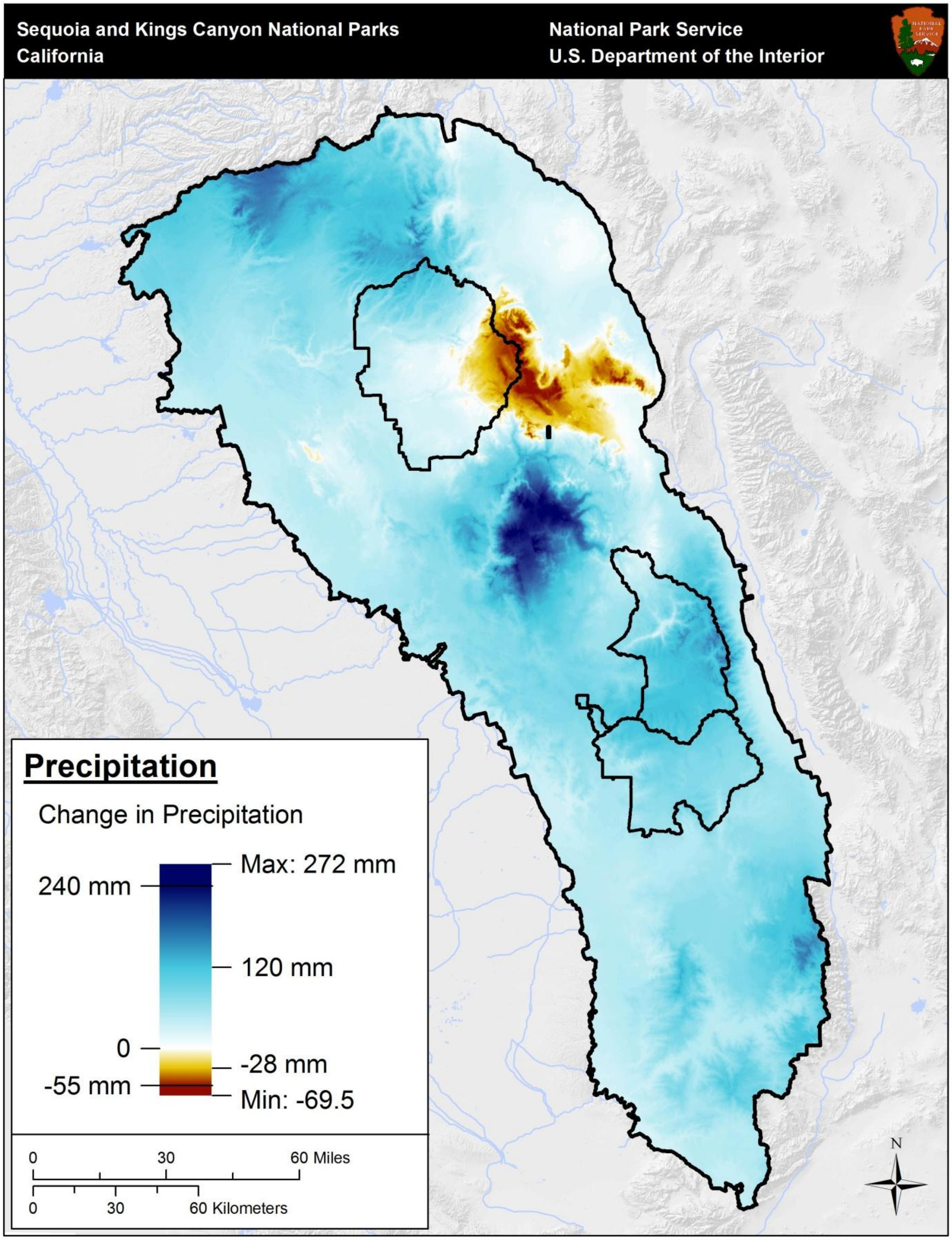
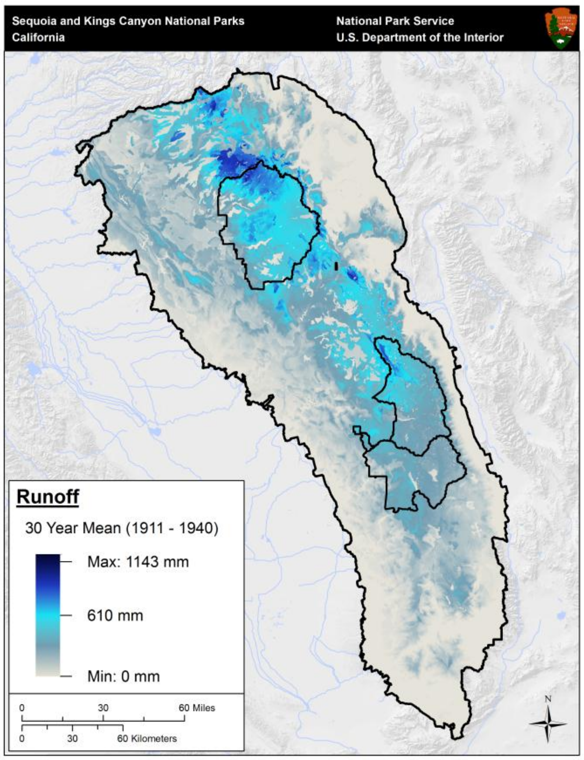
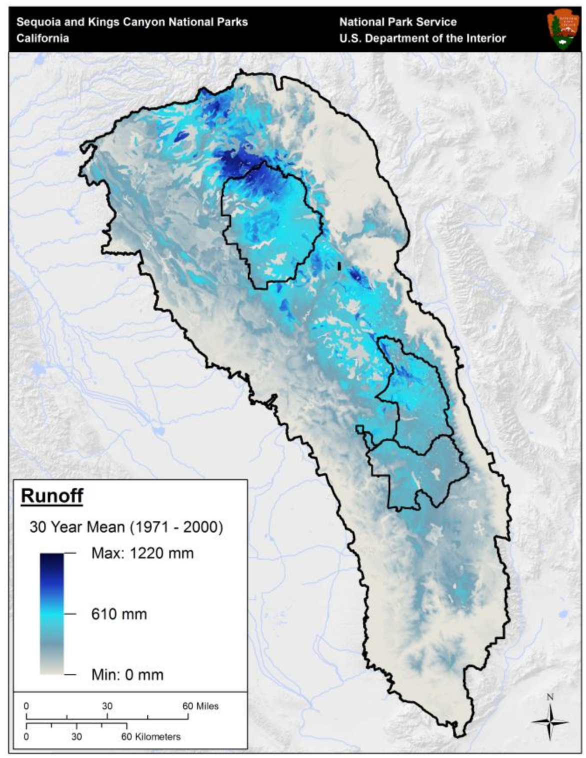


Figure 24. Change in annual precipitation (mm) between a 30-year mean centered of annual values 1911-1940, and from 1971-2000.

Runoff

Changes in runoff were assessed by comparing the two 30-year means (Figures 25, & 26; Tables 13 & 14). Runoff, calculated as $mm/m^2/year$ is the amount of water in the hydrologic model that exceeds soil storage and recharge. Runoff has increased generally in SEKI NP by about 100 mm, with some of the eastern higher mountains in Kings Canyon NP showing a higher runoff, at about 200 mm (Figure 27). The northernmost part of SEKI NP shows the greatest decrease in runoff, at about 150 mm.





Figures 25 & 26. Annual runoff (mm) from 30-year mean centered of annual values 1911-1940, and from 1971-2000.

Table 13. The extent of annual runoff (mm) by quartile of the range on values found within the PACE and SEKI boundaries historically, in current time, and the difference between them.

Runoff				
1911 – 1940 by Quartile	**PACE**		**SEKI NP**	
Classes (mm)	**Area (km^2)**	**Percent**	**Area (km^2)**	**Percent**
0.0 – 305.1	32,066.8	70.9	1,291.2	36.8
305.1 – 610.2	9,915.9	21.9	2,016.9	57.5
610.2 – 915.3	2,434.6	5.4	160.1	4.6
915.3 – 1,220.4	122.3	0.3	0	0
Water	663.5	1.5	38.0	1.1
No Data	0	0	0	0
1971 – 2000 by Quartile	**PACE**		**SEKI NP**	
Classes (mm)	**Area (km^2)**	**Percent**	**Area (km^2)**	**Percent**
0.0 - 305.1	29,705.8	65.7	616.0	17.6
305.1 - 610.2	11,395.0	25.2	2,594.2	74.0
610.2 - 915.3	3,114.3	6.9	254.2	7.3
915.3 – 1,220.4	324.5	0.7	3.8	0.1
Water	663.5	1.5	38.0	1.1
No Data	0	0	0	0
Difference (cur ave - his ave)	**PACE**		**SEKI NP**	
Classes (mm)	**Area (km^2)**	**Percent**	**Area (km^2)**	**Percent**
0.0 - 305.1	-2,361.0	-5.2	-675.2	-1.5
305.1 - 610.2	1,479.1	3.3	577.3	1.3
610.2 - 915.3	679.7	1.5	94.1	0.2
915.3 – 1,220.4	202.2	0.4	3.8	0
Water	0	0	0	0
No Data	0	0	0	0

Table 14. The extent of runoff (mm) by elevation band of the range on values found within the PACE and SEKI boundaries historically, in current time, and the difference between them.

Runoff				
1911 – 1940 by Elevation	**PACE**		**SEKI NP**	
Classes	**Average**	**Standard Deviation**	**Average**	**Standard Deviation**
≥ 3,500	417.3	153.5	364.4	123.1
3,000 – 3,500	404.6	202.7	362.2	136.4
2,500 – 3,000	344.8	241.8	372.0	110.1
2,000 – 2,500	228.6	231.9	361.0	94.9
1,500 – 2,000	179.6	173.9	319.8	112.3
1,000 – 1,500	122.1	122.6	195.8	105.8
0 – 1,000	90.1	92.1	79.9	35.7
1971 – 2000 by Elevation	**PACE**		**SEKI NP**	
Classes	**Average**	**Standard Deviation**	**Average**	**Standard Deviation**
≥ 3,500	397.2	129.4	349.1	80.3
3,000 – 3,500	459.4	198.8	449.4	135.2
2,500 – 3,000	383.5	260.8	450.0	125.0
2,000 – 2,500	265.3	257.0	418.0	95.1
1,500 – 2,000	221.3	198.4	364.1	113.5
1,000 – 1,500	153.8	144.6	224.7	108.4
0 – 1,000	110.9	105.8	98.9	38.7
Difference (cur ave - his ave)	**PACE**		**SEKI NP**	
Classes	**Average**	**Standard Deviation**	**Average**	**Standard Deviation**
≥ 3,500	-20.2	113.8	-15.3	114.2
3,000 – 3,500	54.8	67.1	87.2	78.1
2,500 – 3,000	38.7	37.9	78.0	36.8
2,000 – 2,500	36.7	39.5	57.1	20.1
1,500 – 2,000	41.7	34.3	44.4	13.1
1,000 – 1,500	31.7	26.9	28.9	9.1
0 – 1,000	20.8	16.9	19.0	4.6

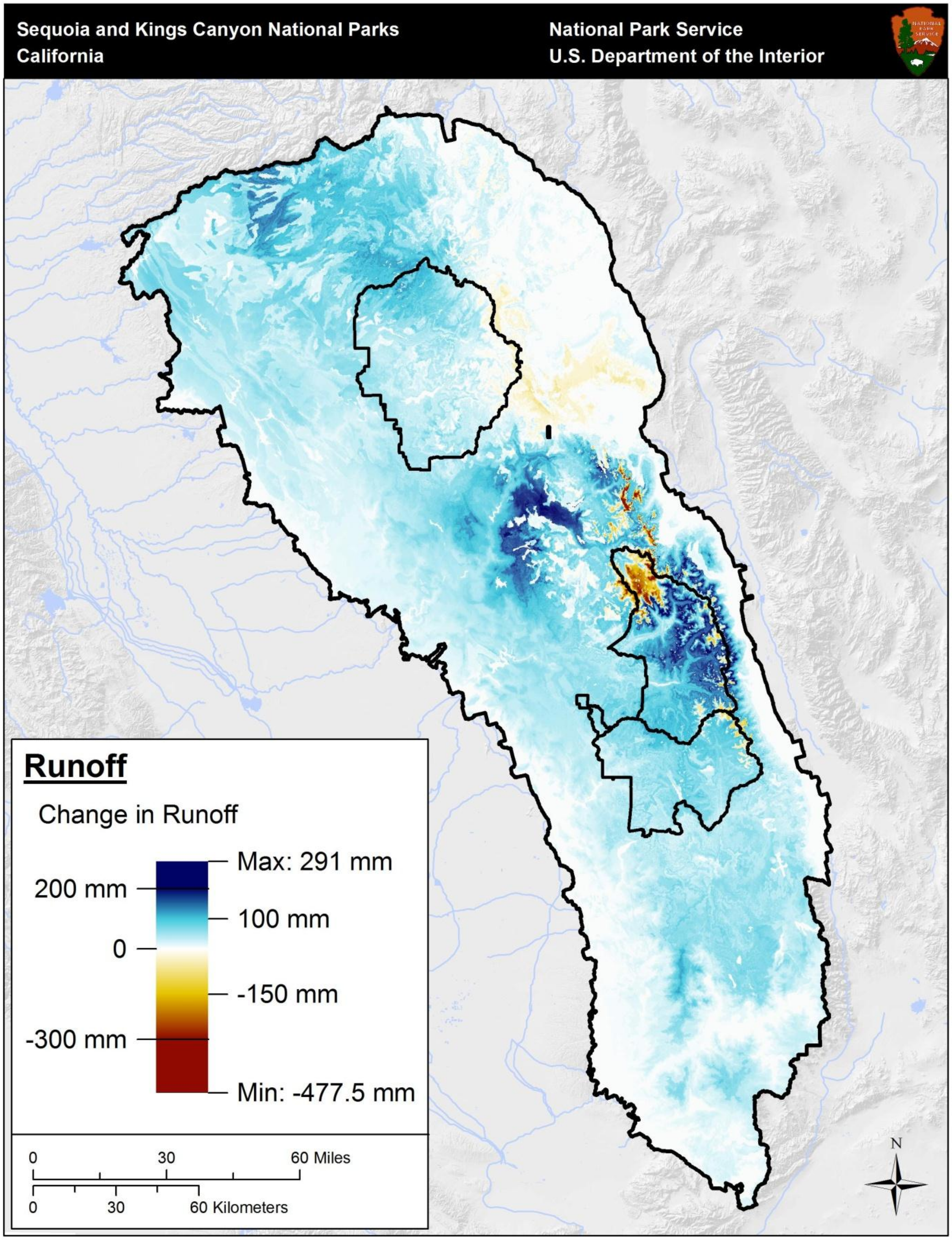
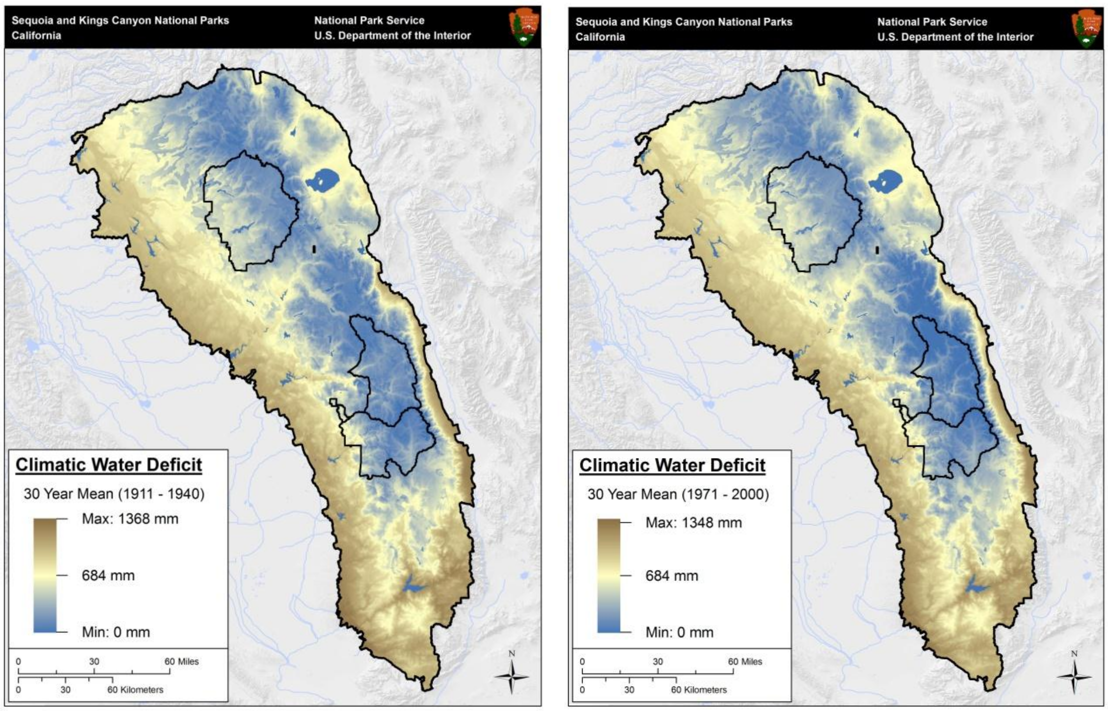


Figure 27. Change in annual runoff (mm) between a 30-year mean centered of annual values 1911-1940, and from 1971-2000.

Climatic Water Deficit

Climatic Water Deficit (CWD) is “evaporative demand not met by available water, a measure of how much more water could have been evaporated or transpired from a site covered by a standard crop, had the water been available. It is related to excess energy in the environment. It is the difference between potential Evapotranspiration and actual Evapotranspiration.” (Stephenson 1990). We calculated Climatic Water Deficit from the downscaled climate data described above (Flint & Flint 2007). Presented here are maps for mean annual CWD) from 1911-1940, 1971-2000 (Figures 28 & 29). We also portray the change between these two time periods (Figure 30), and quantify the results by elevation and by quartile (Tables 15 & 16).



Figures 28 & 29. Annual climatic water deficit in millimeters from a 30-year mean centered of annual values 1911-1940, and from 1971-2000.

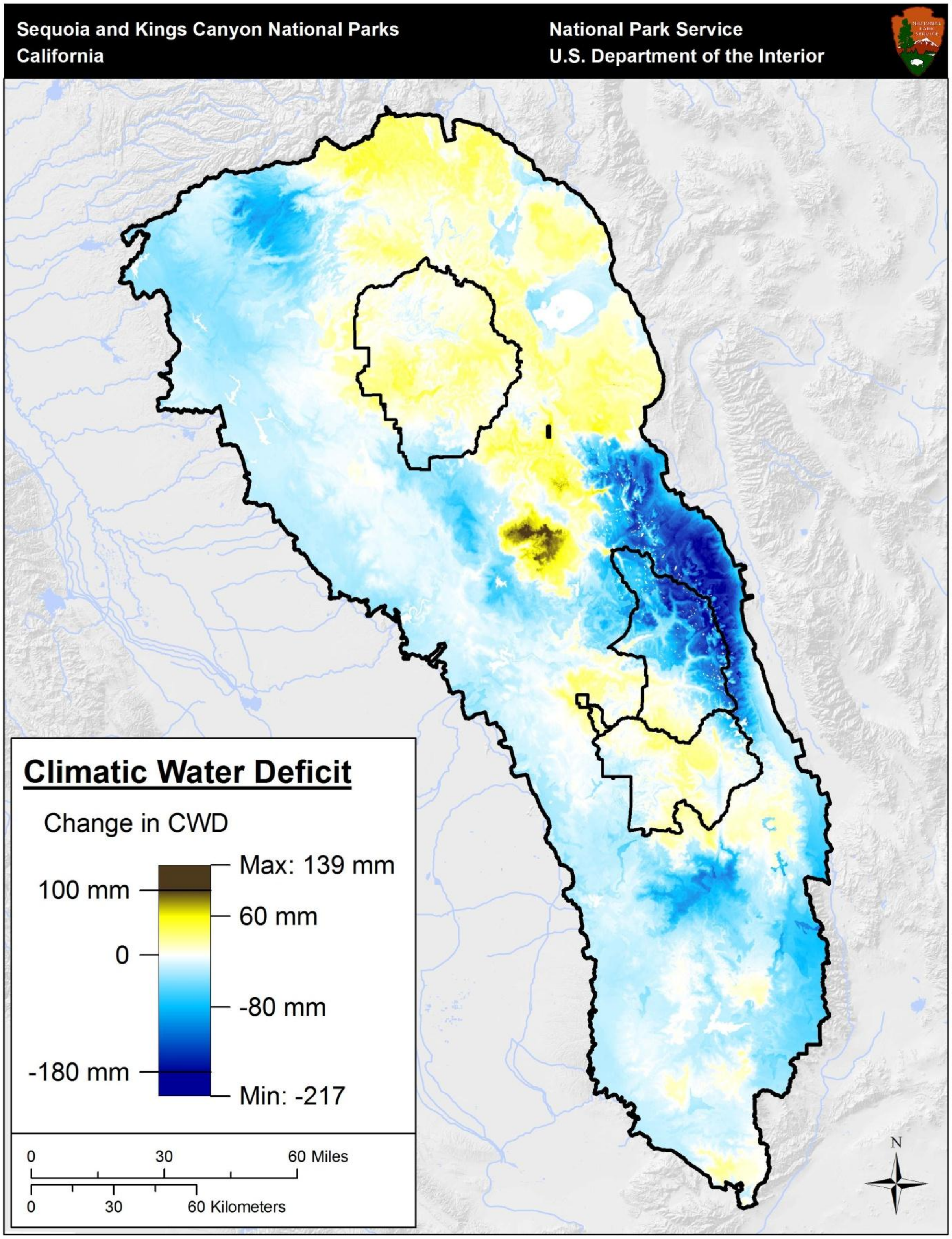


Figure 30. Modeled change in average annual water deficit over 60 years. Increases in water deficit to 60 mm (yellow color) in SEKI NP.

Table 15. The extent of annual climatic water deficit by quartile of the range on values found within the PACE and SEKI boundaries historically, in current time, and the difference between them.

Climatic Water Deficit				
1911 – 1940 by Quartile	**PACE**		**SEKI NP**	
Classes (mm)	**Area (km^2)**	**Percent**	**Area (km^2)**	**Percent**
0.0 – 341.9	12,402.5	27.4	2,963.5	84.5
341.9 – 683.8	13,585.4	30.1	446.2	12.7
683.8 – 1,025.7	13,316.6	29.5	58.5	1.7
1,025.7 – 1,367.7	5,234.9	11.6	0	0
Water	663.5	1.5	38.0	1.1
No Data	0	0	0	0
1971 – 2000 by Quartile	**PACE**		**SEKI NP**	
Classes (mm)	**Area (km^2)**	**Percent**	**Area (km^2)**	**Percent**
0.0 – 341.9	12,543.1	27.7	2,964.7	84.6
341.9 – 683.8	14,001.8	31.0	451.4	12.9
683.8 – 1,025.7	13,547.9	30.0	52.1	1.5
1,025.7 – 1,367.7	4,446.8	9.8	0	0
Water	663.5	1.5	38.0	1.1
No Data	0	0	0	0
Difference (cur ave - hist ave)	**PACE**		**SEKI NP**	
Classes (mm)	**Area (km^2)**	**Percent**	**Area (km^2)**	**Percent**
0.0 – 341.9	140.6	0.3	1.2	0
341.9 – 683.8	416.3	0.9	5.2	0.1
683.8 – 1,025.7	231.2	0.5	-6.3	-0.2
1,025.7 – 1,367.7	-788.1	-1.7	0	0
Water	0	0	0	0
No Data	0	0	0	0

Table 16. The extent of annual climatic water deficit by elevation band of the range on values found within the PACE and SEKI boundaries historically, in current time, and the difference between them.

Climatic Water Deficit				
1911 – 1940 by Elevation	PACE		SEKI NP	
Elevation Classes (m)	Average	Standard Deviation	Average	Standard Deviation
≥ 3,500	82.4	49.5	73.9	46.4
3,000 – 3,500	162.8	90.4	138.2	52.8
2,500 – 3,000	269.9	144.5	202.5	61.5
2,000 – 2,500	477.2	194.7	284.6	85.7
1,500 – 2,000	647.0	237.9	400.1	129.0
1,000 – 1,500	770.7	240.2	554.0	125.2
0 – 1,000	936.2	149.5	766.1	93.1
1971 – 2000 by Elevation	PACE		SEKI NP	
Elevation Classes (m)	Average	Standard Deviation	Average	Standard Deviation
≥ 3,500	27.4	45.0	23.7	35.6
3,000 – 3,500	126.4	100.9	89.8	70.0
2,500 – 3,000	272.5	138.1	186.9	73.9
2,000 – 2,500	474.7	182.6	279.2	87.9
1,500 – 2,000	622.9	230.0	401.8	132.0
1,000 – 1,500	753.9	236.8	548.0	121.5
0 – 1,000	919.8	147.7	750.0	94.0
Difference (cur ave - hist ave)	PACE		SEKI NP	
Elevation Classes (m)	Average	Standard Deviation	Average	Standard Deviation
≥ 3,500	-54.9	52.5	-50.2	53.8
3,000 – 3,500	-36.3	64.3	-48.4	63.7
2,500 – 3,000	2.5	42.0	-15.6	39.8
2,000 – 2,500	-2.7	34.5	-5.5	15.8
1,500 – 2,000	-24.0	35.4	1.7	14.2
1,000 – 1,500	-16.7	21.4	-6.0	11.1
0 – 1,000	-16.5	9.4	-16.1	4.9

Climate Synthesis

The numerous portrayals of climate presented above merit summarization. The region has witnessed several changes through the 20^{th} century. Minimum temperatures have slightly increased in the region, but SEKI has experienced less increase than most of the region. Maximum temperatures have generally decreased across the PACE region, with Tmax in SEKI decreasing more than most of the region, suggesting a muting of daily temperature profiles in recent years relative to earlier in the 20^{th} century. Under future climate scenarios, however, both

Tmin and Tmax values within the PACE are expected to increase by approximately 2 – 6°C by the end of the 21st century. The portrayal of yearly melt and freeze cycles, which were derived from monthly Tmin data, reveal a diminishment of the winter season, as freezing temperatures reach fewer places and last for a shorter period of time. This pattern is projected to continue into the future as the climate warms, but SEKI is well positioned in the southern Sierra to potentially serve as a refuge, because the great extent of high elevation area may permit for some upwards migration, as well as buffer impacts to species that already dwell at high elevations.

Precipitation tends to be higher in the northern parts of the PACE, generally decreasing as one moves south. Historically, precipitation levels were lower throughout the PACE, but some drying has been observed to the east of Yosemite. Runoff tends to broadly follow the same pattern as precipitation, generally decreasing from north to south, but the local patterns vary substantially due to the underlying geology. In the future, runoff patterns may be substantially altered depending on how precipitation patterns change. The seasonal timing of runoff will also change as more precipitation falls as rain, and the snowpack melts earlier in the spring. Relative to adjacent areas, the high elevation Sierra, including SEKI, contribute a substantial proportion of water to stream flow. Runoff has increased since the beginning of the 20th century, following the increase in precipitation, but local patterns can vary due to a number of factors. Climatic Water Deficit (CWD) in the PACE region appears to be lowest in the high elevation areas, including much of SEKI. This would indicate that the vegetation in many areas of SEKI is limited by other factors such as temperature and the length of the growing season. This may change, however, as temperature and precipitation levels change in the future, and some increase in CWD appears to have already occurred in parts of SEKI and around Yosemite.

Vegetation

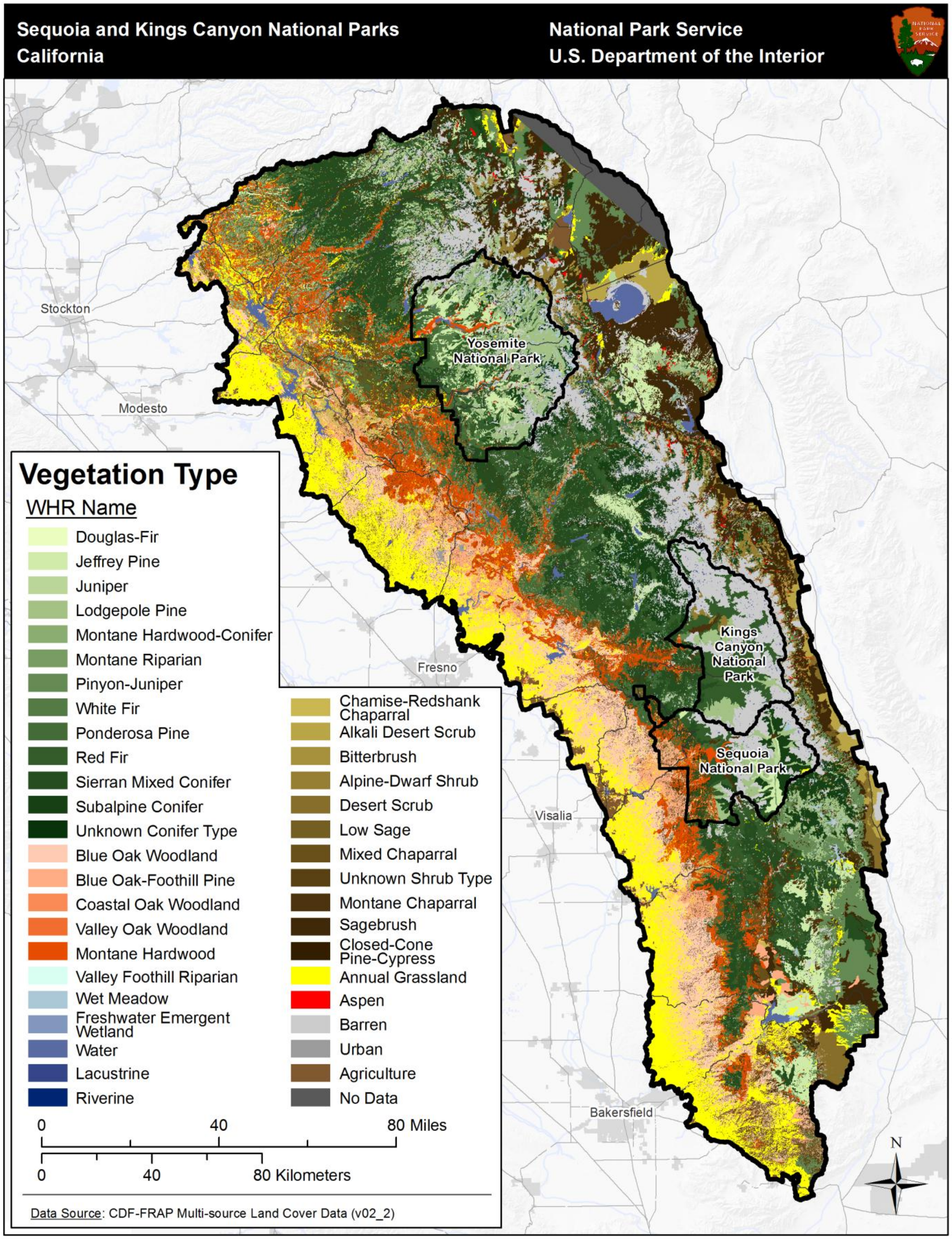
There are numerous state and national landcover or vegetation maps, each with a unique set of landcover classes. These include the LANDFIRE (LANDFIRE 2010) program's national maps, used here to present vegetation structure, or cover, on the landscape, and the California Department of Forestry and Fire Protection's Multi-source vegetation map (FRAP 2002) used here to represent landcover types. We selected the FRAP map (Figure 31) over NatureServe's national landcover or LANDFIRE's national land cover maps because it provided a greater number of California-specific vegetation types. In addition, for vegetation types, the LANDFIRE map has been evaluated at only 41.1% accuracy for the SEKI region (Story et al. 2009).

The extents of the 59 CWHR types in the FRAP map are shown in Table 17. This land coverage demonstrates two important attributes. First, the distribution of land cover types varies considerably between SEKI and the SIEN PACE regional area. The five most common cover classes, regionally, are annual grassland, barrens, Sierra mixed conifer, blue oak woodlands and sagebrush. Combined, these five types make up 46% of the region. In contrast, barrens alone comprise 37.7% of SEKI, with the remaining four types covering a mere 7% of the landscape. The dominant cover types in SEKI are the high elevation cover types (barren, red fir, lodgepole pine, subalpine conifer, Sierra mixed conifer) and together comprise 80.1% of the park area. The Barrens class in WHR does not distinguish between alpine habitats and lower exposed rocks. However, both of these categories may harbor unique species and be of management interest. We therefore used two elevation cutoffs to determine the extent of Barrens in areas that would class to alpine, or 'below alpine': one at 2000 m, and another at 2200 m (Figure 32). In the PACE region, the amount of land in the Barren class which falls above the 2000 m cutoff is 93.1%, compared to 99.8% in SEKI (Table 18). The same pattern is found when using the 2200 m cutoff, where the nearly all of the Barren land in SEKI is found in high elevation alpine areas.

The second major point to note is that there are few unique habitats within SEKI relative to the region. Among the 20 rarest cover types found in the SIEN PACE region (5.3% of land area), only Juniper exceeds 0.5% cover in SEKI, and the suite only covers less than 2% of SEKI. Thus, the most distinctive feature of SEKI, from a land cover perspective is the abundance of its high elevation cover types, most notably barrens. We did not use the national NatureServe map that uses a landscape classification system of over 500 land cover types for the United States as a whole (Comer et al. 2003, map more recent). While this map provided over 1,000,000 pixels for the PACE region, it is composed generally of geographically-keyed classes starting with titles such as "California Montane Woodland and Chaparral", and contained for the Sierras some types associated the Rocky Mountain series. While this type of label does provide information about the physiognomic types in the Parks, it was less informative than using a more California-specific product. We also selected the LANDFIRE map to represent vegetation physiognomic classes (called "cover" in the map) on the landscape (Figure 33), which seemed the most detailed measure available for cover, and for which the accuracy of species within physiognomic units might not be as problematic. Distribution of cover classes by type is shown in Table 19.

Finally, this section also presents the SEKI vegetation map (National Park Service - Sequoia and Kings Canyon National Parks, Division of Resources Management and Science 2007), which has been used extensively in other chapters of this NRCA. It is comprised of 82,086 polygons derived from 1 m^2 imagery and has by far the most landscape classification units for the Parks, as well as likely the highest level of accuracy on the ground (Figure 35 and 36). The SEKI vegetation map uses the Manual of California Vegetation scheme (Sawyer et al 2009) which is a nested classification of the National Vegetation Classification Scheme (NVCS; Federal Geographic Data Committee 2008) and identifies the Parks to Alliance and Association-level map units, in which one or two species are named in the landcover name.

However, the NVCS maps are not available across the entire PACE region, meaning that for regional analyses we were forced to a more generalized classification. Other chapters such as rare plants, biodiversity and the foothills chapter illustrate the great utility that a high quality, high spatial resolution map can provide for park management. While such a digital product is expensive to produce, it proved to be more informative for Park-level analysis, and therefore for management support than any of the other categories of landcover maps that were available. Note that most of the chapters however, use the more general CWHR classification, rather than the NCVS classification of the SEKI vegetation map for their analyses. This is because the 150 types in the NVCS classification reduced other data among too many categories for useful statistical analyses. Authors of the other chapters, however, found the spatial detail in the SEKI map to be particularly useful. For comparison, the vegetation type categories and extents from the SEKI vegetation map are presented for both the CWHR classification (Table 20) and the NVCS classification (Table 21).



.

Figure 31. The PACE region as mapped using the California FRAP landcover map. This map using the California Wildlife Habitat Relationships classification, of 59 land cover classes, here broken into color ramps by physiognomic types. The data used in this map are publically available, and should be used rather than the illustration for any regional analyses.

Table 17. The extent of CWHR types identified in the FRAP landcover map for the PACE and SEKI regions. A blank indicates this type not mapped by FRAP in the SEKI extent.

	Area (ha)		Percent	
WHR Name	**PACE**	**SEKI**	**PACE**	**SEKI**
Agriculture	40,699.3		0.9%	
Alkali Desert Scrub	52,109.4		1.2%	
Alpine-Dwarf Shrub	63,682.4	3,582.1	1.4%	1.0%
Annual Grassland	509,796.8	905.8	11.3%	0.3%
Aspen	10,942.1		0.2%	
Barren	463,506.1	132,163.5	10.3%	37.7%
Bitterbrush	18,181.3		0.4%	
Blue Oak Woodland	330,757.9	2,264.2	7.3%	0.6%
Blue Oak-Foothill Pine	105,134.4	5,530.5	2.3%	1.6%
Chamise-Redshank Chaparral	34,250.2	985.8	0.8%	0.3%
Closed-Cone Pine-Cypress	206.0		0.0%	
Coastal Oak Woodland	51.0		0.0%	
Desert Scrub	29,649.3		0.7%	
Douglas-Fir	9,231.0		0.2%	
Freshwater Emergent Wetland	510.0		0.0%	
Jeffrey Pine	158,939.6	7,753.4	3.5%	2.2%
Juniper	7,323.1	1,813.0	0.2%	0.5%
Lacustrine	173.0		0.0%	
Lodgepole Pine	181,646.2	35,083.9	4.0%	10.0%
Low Sage	4,137.0		0.1%	
Mixed Chaparral	126,200.2	407.5	2.8%	0.1%
Montane Chaparral	107,417.7	4,780.7	2.4%	1.4%
Montane Hardwood	299,342.7	20,829.5	6.6%	5.9%
Montane Hardwood-Conifer	103,259.1	1.9	2.3%	0.0%
Montane Riparian	18,096.3	1,029.4	0.4%	0.3%
Pinyon-Juniper	167,142.3	718.4	3.7%	0.2%
Ponderosa Pine	153,158.2	6,426.4	3.4%	1.8%
Red Fir	274,838.5	70,201.7	6.1%	20.0%
Riverine	2.0		0.0%	
Sagebrush	317,426.2	1.1	7.0%	0.0%
Sierran Mixed Conifer	462,409.2	21,906.5	10.2%	6.3%
Subalpine Conifer	205,332.8	23,684.4	4.5%	6.8%
Unknown Conifer Type	8,855.1	2,304.0	0.2%	0.7%
Unknown Shrub Type	75,258.4	3,045.7	1.7%	0.9%
Urban	17,567.3	49.2	0.4%	0.0%
Valley Foothill Riparian	64.0		0.0%	
Valley Oak Woodland	117.0		0.0%	
Water	69,660.8	4,094.2	1.5%	1.2%
Wet Meadow	25,441.2	797.0	0.6%	0.2%
White Fir	13,794.2		0.3%	
No Data	53,924.9		1.2%	

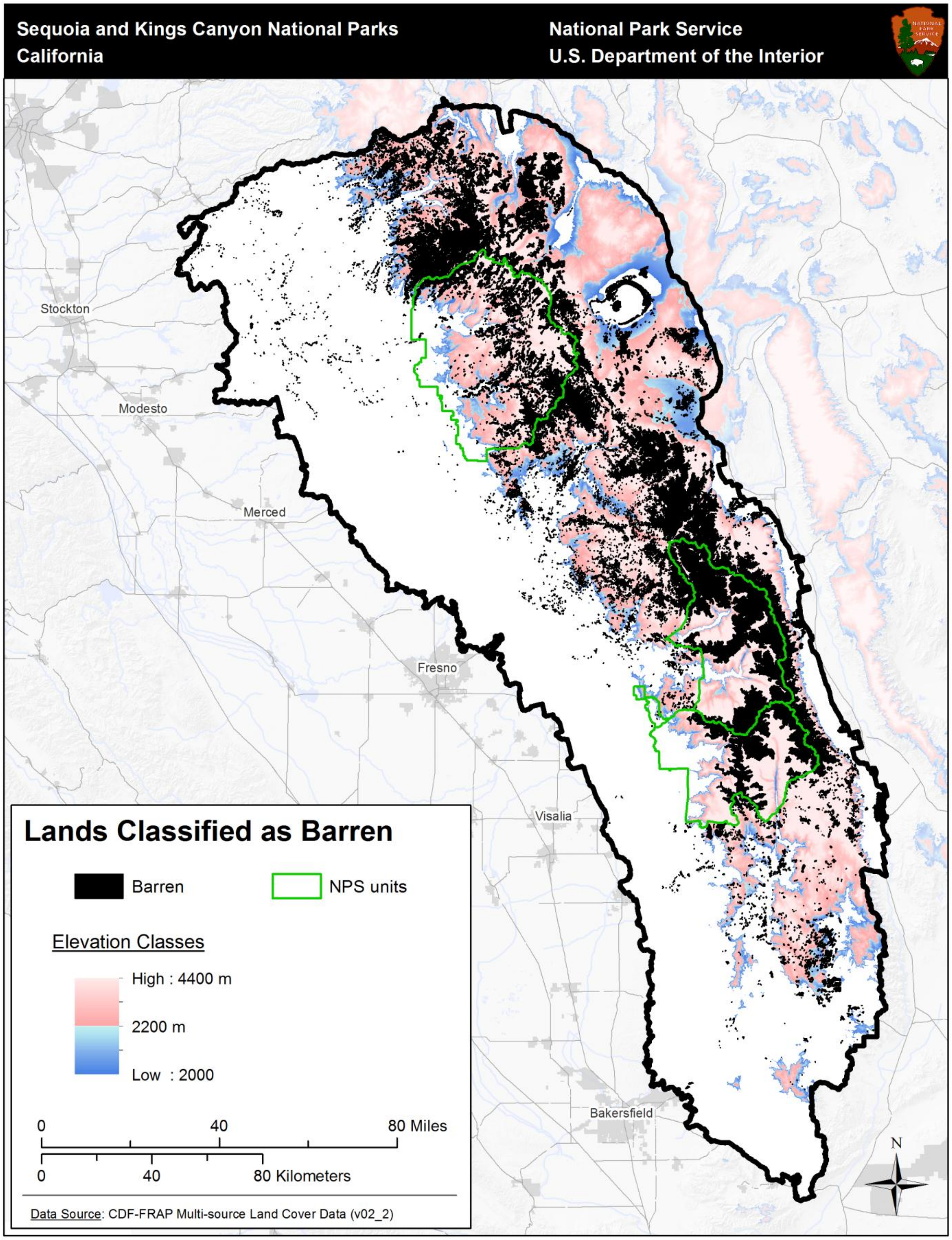


Figure 32. Lands classified in the California FRAP landcover data as barren, shown here overlaid on high elevation areas. The (black) barrens over top of pink occur above 2200m, while those over top of blue are above 2000m.

Table 18. The Barren WHR class broken into Alpine and Non-alpine areas, using two elevation thresholds (2000 and 2200 m) to define the classes.

	Area (ha)		Percent	
2000 m cutoff	**PACE**	**SEKI**	**PACE**	**SEKI**
Alpine	431,625.1	131,889.8	93.1%	99.8%
Non-Alpine	31,880.9	273.7	6.9%	0.2%
2200 m cutoff				
Alpine	417,179.0	131,604.6	90.0%	99.6%
Non-Alpine	46,327.0	558.9	10.0%	0.4%

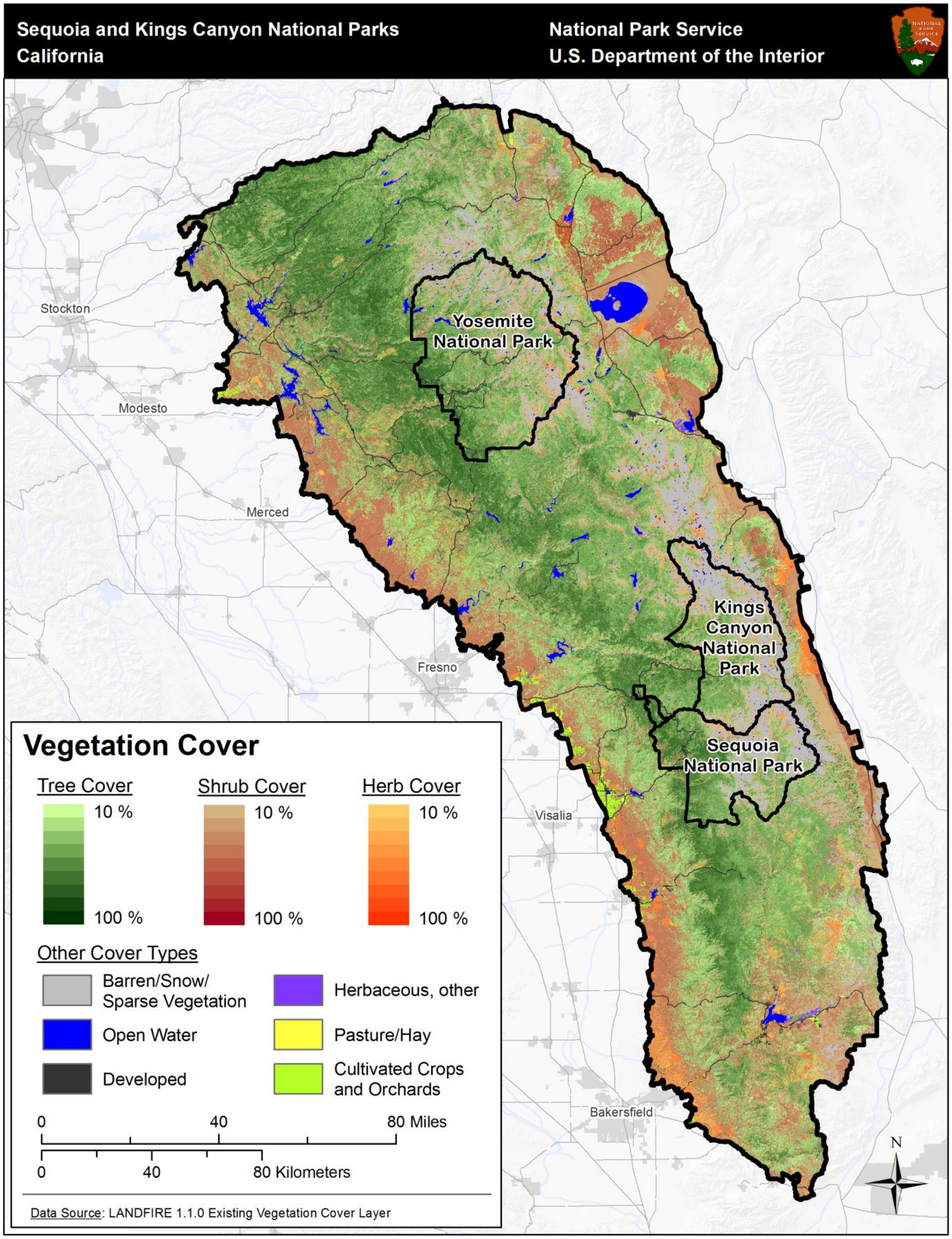


Figure 33. Vegetation structure (cover) as derived from the LANDFIRE map. This map shows the cover of the canopy type and is not a measure of different canopy layers in each pixel. That is, each pixel is assigned a vegetation lifeform type and then a cover density was defined for that type.

Table 19. Level of closed canopy by vegetation type for the PACE and SEKI regions, as measured from the LANDFIRE maps. Types listed from Barren and below do not have a canopy measure, but are included to illustrate the landcover types named in the LANDFIRE map. The PACE and SEKI regions have roughly similar levels of tree and herd extents, but the PACE region shows more shrublands, particularly in the 40-50% density class. This is due to the PACE region having proportionally more area in the elevations where mixed chaparral occurs.

	PACE	SEKI		PACE	SEKI
CLASSNAMES	**Area (km^2)**	**Area (km^2)**		**Percent**	**Percent**
Tree Cover >= 10 and < 20%	1,327.3	41.4		2.9%	1.2%
Tree Cover >= 20 and < 30%	4,493.5	218.5		9.9%	6.2%
Tree Cover >= 30 and < 40%	6,630.9	437.1		14.7%	12.5%
Tree Cover >= 40 and < 50%	5,682.8	521.2		12.6%	14.9%
Tree Cover >= 50 and < 60%	3,178.7	230.2		7.0%	6.6%
Tree Cover >= 60 and < 70%	4,116.1	257.4		9.1%	7.3%
Tree Cover >= 70 and < 80%	443.4	33.3		1.0%	1.0%
Tree Cover >= 80 and < 90%	74.1	3.1		0.2%	0.1%
Tree Cover >= 90 and <= 100%	0.1	0.0		0.0%	0.0%
Shrub Cover >= 10 and < 20%	1,963.3	176.9		4.3%	5.0%
Shrub Cover >= 20 and < 30%	415.4	2.7		0.9%	0.1%
Shrub Cover >= 30 and < 40%	551.6	3.7		1.2%	0.1%
Shrub Cover >= 40 and < 50%	6,370.6	61.9		14.1%	1.8%
Shrub Cover >= 50 and < 60%	995.7	16.3		2.2%	0.5%
Shrub Cover >= 60 and < 70%	782.1	22.7		1.7%	0.6%
Shrub Cover >= 70 and < 80%	211.4	8.1		0.5%	0.2%
Shrub Cover >= 80 and < 90%	23.7	1.4		0.1%	0.0%
Shrub Cover >= 90 and <= 100%	3.7	0.4		0.0%	0.0%
Herb Cover >= 10 and < 20%	96.1	21.7		0.2%	0.6%
Herb Cover >= 20 and < 30%	883.3	135.3		2.0%	3.9%
Herb Cover >= 30 and < 40%	348.1	18.4		0.8%	0.5%
Herb Cover >= 40 and < 50%	214.8	29.0		0.5%	0.8%
Herb Cover >= 50 and < 60%	533.4	30.0		1.2%	0.9%
Herb Cover >= 60 and < 70%	107.2	16.7		0.2%	0.5%
Herb Cover >= 70 and < 80%	46.7	4.4		0.1%	0.1%
Herb Cover >= 80 and < 90%	26.2	0.3		0.1%	0.0%
Herb Cover >= 90 and <= 100%	3.8	0.0		0.0%	0.0%
Barren	3,196.0	1,095.6		7.1%	31.3%
Snow/Ice	19.2	3.3		0.0%	0.1%
Sparse Vegetation Canopy	997.5	71.4		2.2%	2.0%
	PACE	**SEKI**		**PACE**	**SEKI**

CLASSNAMES	Area (km^2)	Area (km^2)		Percent	Percent
Open Water	616.4	30.4		1.4%	0.9%
Developed - Upland Deciduous Forest	30.1	0.7		0.1%	0.0%
Developed - Upland Evergreen Forest	41.6	3.1		0.1%	0.1%
Developed - Upland Mixed Forest	9.4	0.4		0.0%	0.0%
Developed - Upland Herbaceous	62.4	0.2		0.1%	0.0%
Developed - Upland Shrubland	41.2	0.2		0.1%	0.0%
Developed - Open Space	3.6	0.0		0.0%	0.0%
Developed - Low Intensity	0.6	0.0		0.0%	0.0%
Developed - Medium Intensity	8.6	0.0		0.0%	0.0%
Developed - High Intensity	2.1	0.0		0.0%	0.0%
Developed-Roads	209.8	1.4		0.5%	0.0%
Herbaceous Semi-dry	1.0	0.0		0.0%	0.0%
Herbaceous Semi-wet	0.6	0.0		0.0%	0.0%
Herbaceous Wetlands	81.8	3.7		0.2%	0.1%
Pasture/Hay	31.7	0.0		0.1%	0.0%
NASS-Pasture and Hayland	79.0	0.0		0.2%	0.0%
Cultivated Crops	138.0	0.0		0.3%	0.0%
NASS-Orchard	78.3	0.0		0.2%	0.0%
NASS-Vineyard	3.2	0.0		0.0%	0.0%
NASS-Row Crop-Close Grown Crop	2.9	0.0		0.0%	0.0%
NASS-Row Crop	2.2	0.0		0.0%	0.0%
NASS-Close Grown Crop	13.8	0.0		0.0%	0.0%
Not show on map legend:	0.0	0.0			
Recently Disturbed Forest	2.0	1.0		0.0%	0.0%
Quarries-Strip Mines-Gravel Pits	7.4	0.0		0.0%	0.0%

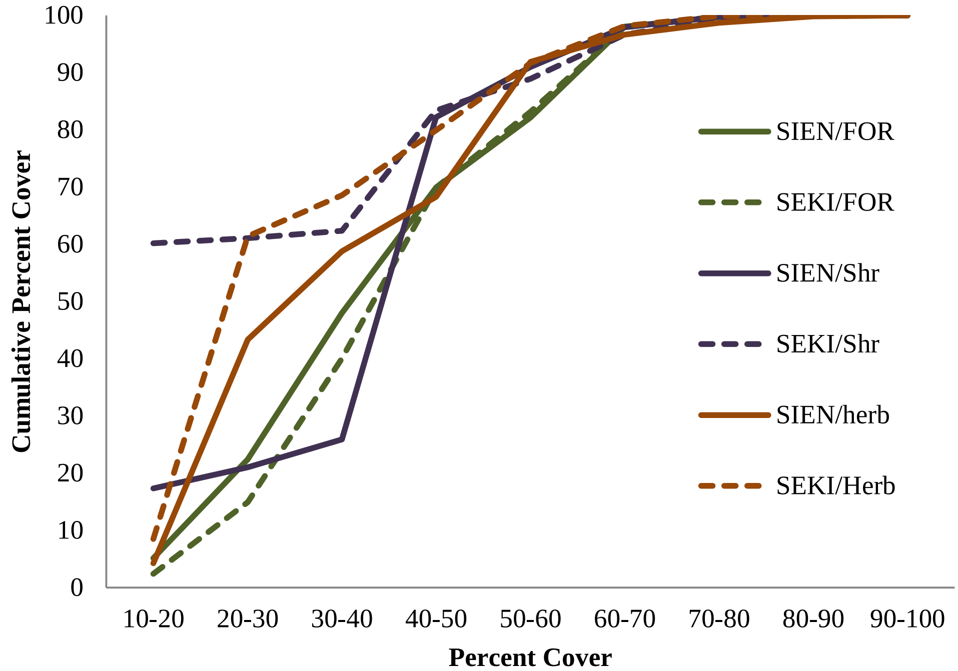


Figure 34. Cumulative percent cover for physiognomic vegetation types. The PACE and SEKI regions have roughly similar levels of tree and herd extents, but the PACE region shows more shrublands, particularly at the 40-50% density class. This is due to the PACE region having proportionally more area in the elevations where mixed chaparral occurs.

We compared the cumulative percent cover of SEKI to the region for forest (green), shrub (purple) and herbaceous (orange) cover types. SEKI cover closely reflects regional cover in forest and herbaceous dominated communities. A striking distinction of SEKI relative to the region is the high fraction of relatively open shrublands, with 60% of shrubland area containing less than 20% cover, compared to 17% for the PACE region (Figure 34 above; SIEN is approximately the same area as PACE). This suggests that there may be some ecological differences in the attributes of shrublands within the park, and in the region. Alternatively, this difference may be due to the finer level of detail captured in the SEKI NP vegetation map. This remains an open question.

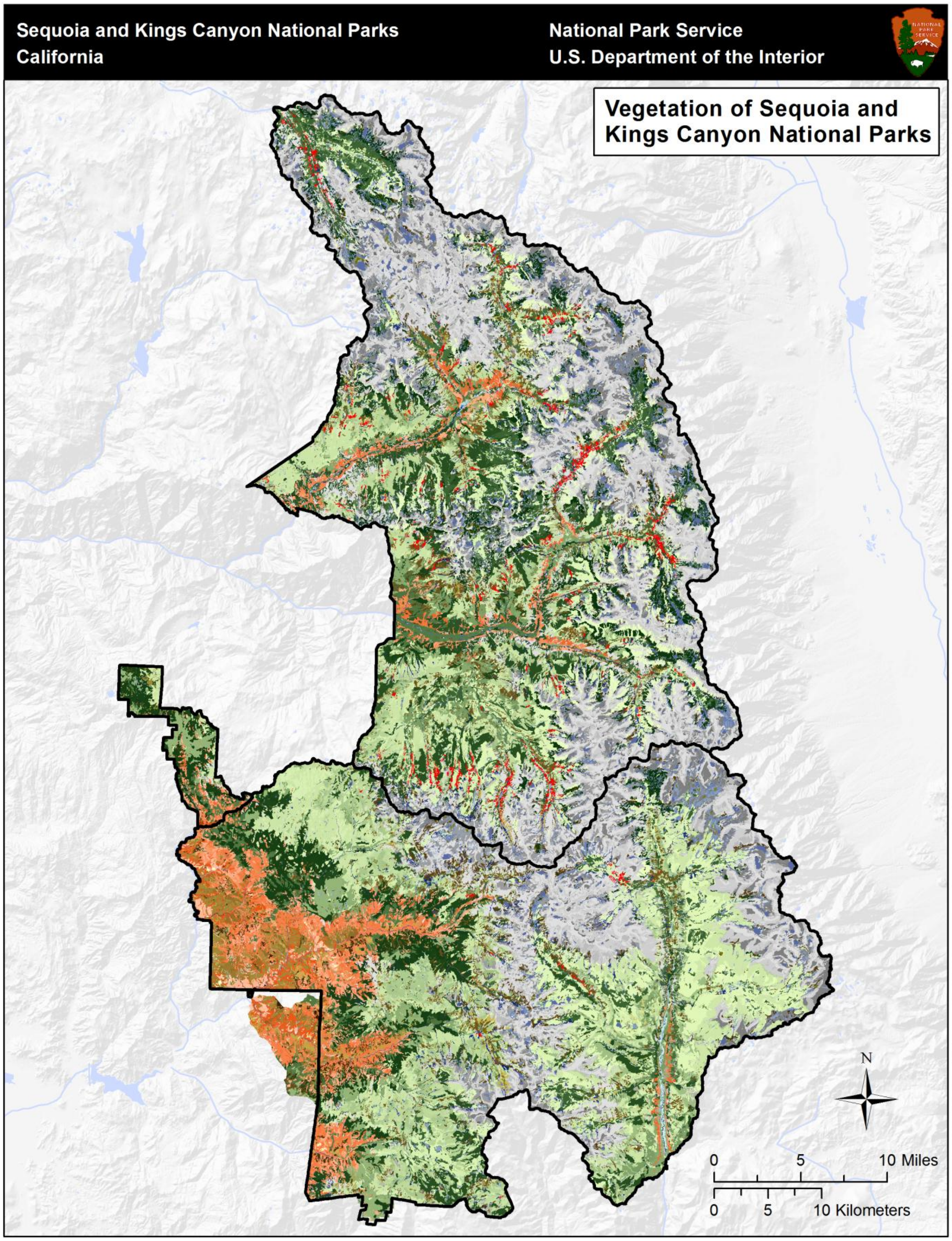


Figure 35. The SEKI vegetation map, built on the NVCS and 1 m resolution imagery. The map portrays 151 landcover classes (Figure 36) across 82,086 polygons. The map and legend are included here for comparative purposes to the PACE vegetation map presented earlier. The vegetation types have been generalized to show the patterns of vegetation by elevation. Any analyses using the SEKI vegetation map should use the actual data. Since the region lacks as detailed a map, comparisons at the regional level will typically use either the WHR classification or the US Forest Service's CalVeg landcover classification. However, for Parks-specific analyses, the SEKI vegetation map provides unparalleled levels of utility, as is illustrated by its use in many of the other chapters of the NRCA.

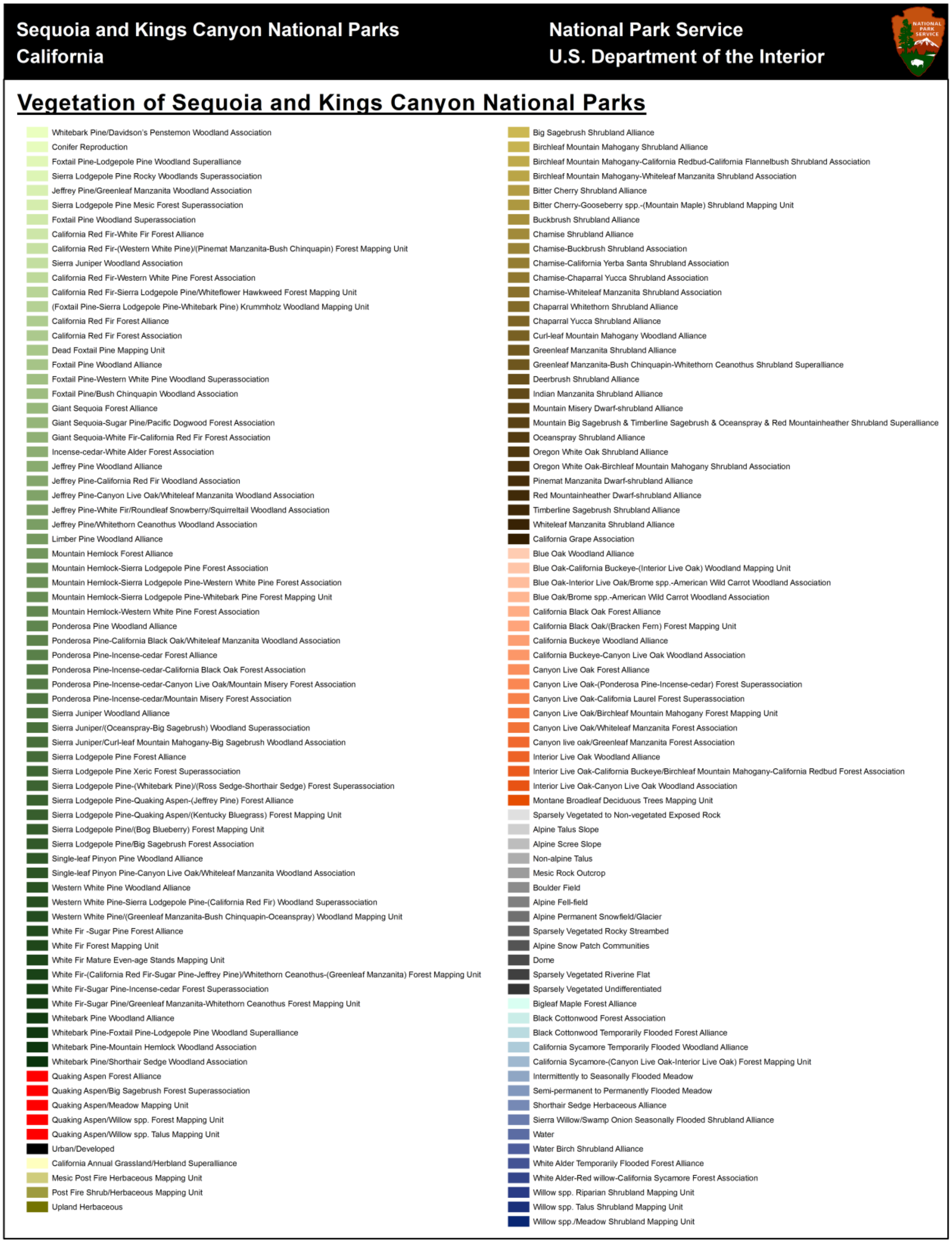


Figure 36. The vegetation types mapped in SEKI using the NVCS mapping system. While there are too many vegetation types to easily be read, this image is included to point out the level of detail developed in the SEKI NP vegetation map.

Table 20. Vegetation extents in SEKI using the CWHR classification.

California Wildlife Habitat Relationship (CWHR) Types	CWHR Code	km^2
Alpine Dwarf Shrub	ADS	6.7
Annual Grass	AGS	2.1
Aspen	ASP	24.9
Barren	BAR	1,122.6
Blue Oak Woodland	BOW	6.6
Chamise - Redshank Chaparral	CRC	40.3
Jeffrey Pine	JPN	164.9
Juniper	JUN	84.9
Lodgepole Pine	LPN	206.9
Mixed Chaparral	MCH	28.6
Montane Chaparral	MCP	123.8
Montane Hardwood	MHW	215.1
Montane Riparian	MRI	8.5
Montane Riparian (modified)	MRI	79.0
Perennial Grass	PGS	11.1
Pinyon - Juniper	PJN	31.0
Ponderosa Pine	PPN	2.0
Red Fir	RFR	199.7
Sagebrush	SGB	62.5
Sagebrush (modified)	SGB	2.7
Sierra Mixed Conifer	SEG	46.1
Sierra Mixed Conifer	SMC	311.5
Subalpine Conifer	SCN	581.0
Urban	URB	0.3
Valley Foothill Riparian	VRI	1.4
Water	WAT	47.2
Wet Meadow	WTM	80.9
White Fir	WFR	52.5

Table 21. The vegetation type extents in SEKI using the NVCS and Manual of California Vegetation classes, also shown in Figure 35 above.

Common Name	Area (km^2)	Percent
Sparsely Vegetated to Non-vegetated Exposed Rock	476.6	13.4%
Alpine Talus Slope	292.8	8.3%
California Red Fir-White Fir Forest Alliance	129.7	3.7%
Alpine Fell-field	111.0	3.1%
Foxtail Pine-Lodgepole Pine Woodland Superalliance	107.6	3.0%
Western White Pine-Sierra Lodgepole Pine-(California Red Fir) Woodland Superassociation	102.5	2.9%
White Fir-Sugar Pine-Incense-cedar Forest Superassociation	100.3	2.8%
Mesic Rock Outcrop	92.5	2.6%
Foxtail Pine Woodland Superassociation	85.7	2.4%
Sierra Lodgepole Pine-(Whitebark Pine)/(Ross Sedge-Shorthair Sedge) Forest Superassociation	85.5	2.4%
Greenleaf Manzanita-Bush Chinquapin-Whitethorn Ceanothus Shrubland Superalliance	80.9	2.3%
Alpine Scree Slope	76.1	2.1%
Whitebark Pine/DavidsonÆs Penstemon Woodland Association	72.2	2.0%
Jeffrey Pine/Greenleaf Manzanita Woodland Association	70.7	2.0%
Whitebark Pine/Shorthair Sedge Woodland Association	62.6	1.8%
California Red Fir-Western White Pine Forest Association	58.2	1.6%
Intermittently to Seasonally Flooded Meadow	56.5	1.6%
Canyon Live Oak-California Laurel Forest Superassociation	49.9	1.4%
Mountain Big Sagebrush & Timberline Sagebrush & Oceanspray & Red Mountainheather Shrubland Superalliance	49.8	1.4%
Sierra Lodgepole Pine Mesic Forest Superassociation	49.7	1.4%
Sierra Lodgepole Pine Rocky Woodlands Superassociation	49.4	1.4%
California Black Oak Forest Alliance	48.8	1.4%
California Red Fir-(Western White Pine)/(Pinemat Manzanita-Bush Chinquapin) Forest Mapping Unit	47.8	1.3%
Water	47.2	1.3%
Jeffrey Pine Woodland Alliance	44.9	1.3%
California Red Fir-Sierra Lodgepole Pine/Whiteflower Hawkweed Forest Mapping Unit	44.6	1.3%
California Red Fir Forest Association	43.4	1.2%
Sierra Juniper Woodland Association	42.9	1.2%
Giant Sequoia-Sugar Pine/Pacific Dogwood Forest Association	38.7	1.1%
Jeffrey Pine-White Fir/Roundleaf Snowberry/Squirreltail Woodland Association	38.5	1.1%
Whitebark Pine-Foxtail Pine-Lodgepole Pine Woodland Superalliance	36.0	1.0%

Common Name	Area (km^2)	Percent
Sierra Willow/Swamp Onion Seasonally Flooded Shrubland Alliance	33.7	1.0%
Boulder Field	33.4	0.9%
Single-leaf Pinyon Pine-Canyon Live Oak/Whiteleaf Manzanita Woodland Association	30.6	0.9%
Canyon Live Oak Forest Alliance	30.3	0.9%
Non-alpine Talus	29.5	0.8%
Foxtail Pine-Western White Pine Woodland Superassociation	28.3	0.8%
Conifer Reproduction	26.7	0.8%
Ponderosa Pine-Incense-cedar/Mountain Misery Forest Association	24.5	0.7%
Chamise Shrubland Alliance	23.6	0.7%
Ponderosa Pine-Incense-cedar-California Black Oak Forest Association	23.1	0.7%
Willow spp. Riparian Shrubland Mapping Unit	21.0	0.6%
White Fir Forest Mapping Unit	20.8	0.6%
Canyon live oak/Greenleaf Manzanita Forest Association	18.4	0.5%
Foxtail Pine/Bush Chinquapin Woodland Association	18.3	0.5%
Sierra Juniper/(Oceanspray-Big Sagebrush) Woodland Superassociation	17.5	0.5%
Interior Live Oak-California Buckeye/Birchleaf Mountain Mahogany-California Redbud Forest Association	17.4	0.5%
Shorthair Sedge Herbaceous Alliance	17.0	0.5%
Willow spp. Talus Shrubland Mapping Unit	15.5	0.4%
Sierra Juniper/Curl-leaf Mountain Mahogany-Big Sagebrush Woodland Association	13.7	0.4%
White Fir Mature Even-age Stands Mapping Unit	13.3	0.4%
Bitter Cherry-Gooseberry spp.-(Mountain Maple) Shrubland Mapping Unit	13.2	0.4%
Big Sagebrush Shrubland Alliance	12.8	0.4%
White Fir-Sugar Pine/Greenleaf Manzanita-Whitethorn Ceanothus Forest Mapping Unit	12.5	0.4%
Jeffrey Pine-California Red Fir Woodland Association	12.5	0.4%
Whitebark Pine Woodland Alliance	11.6	0.3%
Sierra Juniper Woodland Alliance	10.8	0.3%
Quaking Aspen/Big Sagebrush Forest Superassociation	10.7	0.3%
Canyon Live Oak/Birchleaf Mountain Mahogany Forest Mapping Unit	10.0	0.3%
Western White Pine/(Greenleaf Manzanita-Bush Chinquapin-Oceanspray) Woodland Mapping Unit	10.0	0.3%
Canyon Live Oak/Whiteleaf Manzanita Forest Association	9.9	0.3%
Chamise-Whiteleaf Manzanita Shrubland Association	9.8	0.3%
Oregon White Oak-Birchleaf Mountain Mahogany Shrubland Association	9.4	0.3%
Upland Herbaceous	9.0	0.3%
Greenleaf Manzanita Shrubland Alliance	8.8	0.2%

Common Name	Area (km^2)	Percent
Sierra Lodgepole Pine Xeric Forest Superassociation	8.8	0.2%
Willow spp./Meadow Shrubland Mapping Unit	8.2	0.2%
Canyon Live Oak-(Ponderosa Pine-Incense-cedar) Forest Superassociation	8.2	0.2%
White Fir -Sugar Pine Forest Alliance	7.9	0.2%
Sierra Lodgepole Pine/(Bog Blueberry) Forest Mapping Unit	7.6	0.2%
Western White Pine Woodland Alliance	7.4	0.2%
Semi-permanent to Permanently Flooded Meadow	7.2	0.2%
Interior Live Oak-Canyon Live Oak Woodland Association	6.5	0.2%
Birchleaf Mountain Mahogany Shrubland Alliance	6.5	0.2%
Jeffrey Pine-Canyon Live Oak/Whiteleaf Manzanita Woodland Association	6.4	0.2%
Chamise-California Yerba Santa Shrubland Association	6.3	0.2%
Birchleaf Mountain Mahogany-Whiteleaf Manzanita Shrubland Association	6.1	0.2%
Giant Sequoia-White Fir-California Red Fir Forest Association	6.0	0.2%
Quaking Aspen Forest Alliance	6.0	0.2%
White Fir-(California Red Fir-Sugar Pine-Jeffrey Pine)/Whitethorn Ceanothus-(Greenleaf Manzanita) Forest Mapping Unit	6.0	0.2%
Quaking Aspen/Willow spp. Talus Mapping Unit	5.9	0.2%
California Buckeye-Canyon Live Oak Woodland Association	5.7	0.2%
California Red Fir Forest Alliance	5.7	0.2%
Ponderosa Pine-Incense-cedar-Canyon Live Oak/Mountain Misery Forest Association	5.0	0.1%
Alpine Permanent Snowfield/Glacier	4.9	0.1%
Deerbrush Shrubland Alliance	4.9	0.1%
Jeffrey Pine/Whitethorn Ceanothus Woodland Association	4.4	0.1%
Dead Foxtail Pine Mapping Unit	4.1	0.1%
Red Mountainheather Dwarf-shrubland Alliance	4.1	0.1%
Blue Oak-Interior Live Oak/Brome spp.-American Wild Carrot Woodland Association	4.1	0.1%
Interior Live Oak Woodland Alliance	4.0	0.1%
Blue Oak-California Buckeye-(Interior Live Oak) Woodland Mapping Unit	4.0	0.1%
Birchleaf Mountain Mahogany-California Redbud-California Flannelbush Shrubland Association	3.8	0.1%
Black Cottonwood Forest Association	3.4	0.1%
Bitter Cherry Shrubland Alliance	3.3	0.1%
(Foxtail Pine-Sierra Lodgepole Pine-Whitebark Pine) Krummholz Woodland Mapping Unit	3.2	0.1%
Sparsely Vegetated Rocky Streambed	3.0	0.1%
Ponderosa Pine-Incense-cedar Forest Alliance	2.8	0.1%

Common Name	Area (km^2)	Percent
Curl-leaf Mountain Mahogany Woodland Alliance	2.7	0.1%
Indian Manzanita Shrubland Alliance	2.6	0.1%
Post Fire Shrub/Herbaceous Mapping Unit	2.5	0.1%
Blue Oak/Brome spp.-American Wild Carrot Woodland Association	2.5	0.1%
Sierra Lodgepole Pine Forest Alliance	2.3	0.1%
Limber Pine Woodland Alliance	2.2	0.1%
Whiteleaf Manzanita Shrubland Alliance	2.2	0.1%
Mesic Post Fire Herbaceous Mapping Unit	2.1	0.1%
Mountain Hemlock-Sierra Lodgepole Pine-Western White Pine Forest Association	2.1	0.1%
California Annual Grassland/Herbland Superalliance	2.1	0.1%
Black Cottonwood Temporarily Flooded Forest Alliance	2.0	0.1%
Quaking Aspen/Willow spp. Forest Mapping Unit	2.0	0.1%
Chaparral Yucca Shrubland Alliance	1.9	0.1%
White Alder Temporarily Flooded Forest Alliance	1.8	0.1%
Chamise-Buckbrush Shrubland Association	1.8	0.1%
Oceanspray Shrubland Alliance	1.6	0.0%
California Black Oak/(Bracken Fern) Forest Mapping Unit	1.6	0.0%
Sierra Lodgepole Pine/Big Sagebrush Forest Association	1.4	0.0%
Giant Sequoia Forest Alliance	1.4	0.0%
Incense-cedar-White Alder Forest Association	1.3	0.0%
California Sycamore-(Canyon Live Oak-Interior Live Oak) Forest Mapping Unit	1.3	0.0%
Pinemat Manzanita Dwarf-shrubland Alliance	1.2	0.0%
Sierra Lodgepole Pine-Quaking Aspen-(Jeffrey Pine) Forest Alliance	1.2	0.0%
Mountain Hemlock-Western White Pine Forest Association	1.2	0.0%
Mountain Misery Dwarf-shrubland Alliance	1.2	0.0%
Mountain Hemlock-Sierra Lodgepole Pine-Whitebark Pine Forest Mapping Unit	1.2	0.0%
Ponderosa Pine-California Black Oak/Whiteleaf Manzanita Woodland Association	1.1	0.0%
Sparsely Vegetated Undifferentiated	1.0	0.0%
Timberline Sagebrush Shrubland Alliance	1.0	0.0%
Mountain Hemlock-Sierra Lodgepole Pine Forest Association	1.0	0.0%
Oregon White Oak Shrubland Alliance	0.9	0.0%
Dome	0.9	0.0%
Sierra Lodgepole Pine-Quaking Aspen/(Kentucky Bluegrass) Forest Mapping Unit	0.9	0.0%
Ponderosa Pine Woodland Alliance	0.8	0.0%
Bigleaf Maple Forest Alliance	0.8	0.0%

Common Name	**Area (km^2)**	**Percent**
Chaparral Whitethorn Shrubland Alliance	0.8	0.0%
Whitebark Pine-Mountain Hemlock Woodland Association	0.7	0.0%
Sparsely Vegetated Riverine Flat	0.7	0.0%
Chamise-Chaparral Yucca Shrubland Association	0.6	0.0%
Water Birch Shrubland Alliance	0.6	0.0%
Foxtail Pine Woodland Alliance	0.6	0.0%
White Alder-Red willow-California Sycamore Forest Association	0.5	0.0%
Buckbrush Shrubland Alliance	0.4	0.0%
Single-leaf Pinyon Pine Woodland Alliance	0.4	0.0%
California Buckeye Woodland Alliance	0.3	0.0%
Quaking Aspen/Meadow Mapping Unit	0.3	0.0%
Urban/Developed	0.3	0.0%
Mountain Hemlock Forest Alliance	0.2	0.0%
Alpine Snow Patch Communities	0.1	0.0%
California Sycamore Temporarily Flooded Woodland Alliance	0.1	0.0%
California Grape Association	0.0	0.0%
Montane Broadleaf Deciduous Trees Mapping Unit	0.0	0.0%
Blue Oak Woodland Alliance	0.0	0.0%

Standing Carbon (TNC SSP) and Gross Primary Productivity

We show two measures of standing carbon. The capacity to measure or model standing carbon is still a relatively new endeavor and there are limitations to both the approaches presented here. However, since the results and the data were available, they were incorporated for this chapter. The standing stock of carbon is of interest with relation to climate change because it represents carbon that is sequestered. Such carbon is therefore not contributing to greenhouse gas concentrations in the atmosphere, but presents a possible addition if it were to burn. The carbon dynamics of the landscape also represent the potential for the sequestration of more carbon over time.

The first data were obtained from the SSP report, and portray standing tree biomass estimates, multiplied by 0.5 to represent the carbon proportion of that biomass (Figure 37). Values within the PACE boundary ranged from 0-302 Mg/ha. Dividing that range into four equal intervals produced breakpoints at: 0% = 0; 25% = 75.5; 50% = 151; 75% = 226.5; and 100% = 302 Mg/ha. The 100 m raster was then reclassified for the area within the PACE boundary (Table 22). These data demonstrate that SEKI has a larger portion of its landscape in each of the higher standing biomass categories than the region as a whole. In fact, over twice the percentage of land cover in the 227-302 Mg/ha category, and approximately 50% more in the 152-226 Mg/ha and the 76-151 Mg/ha categories.

Table 22. Standing Carbon extents in the PACE and SEKI by quartiles.

	PACE		SEKI NP	
Classes (Mg/ha)	**Area (km^2)**	**Percent**	**Area (km^2)**	**Percent**
0 – 75	37,211.3	82.3	2,628.1	75.0
76 – 151	5,400.2	11.9	585.4	16.7
152 – 226	1,472.5	3.3	190.1	5.4
227 – 302	605.3	1.3	100.2	2.9
No Data	513.5	1.1	0.0	0.0

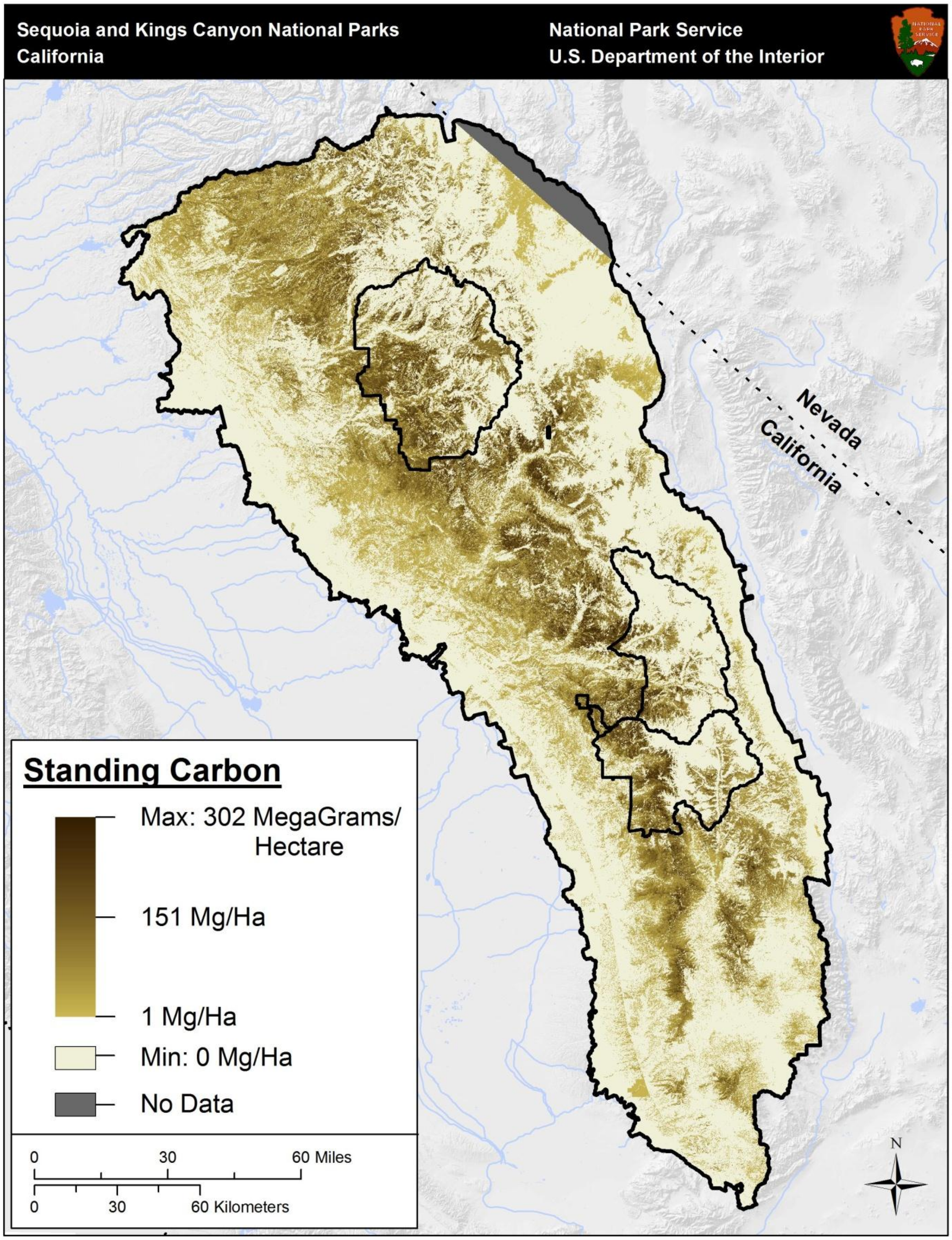


Figure 37. Standing Carbon in the Southern Sierra region.

The second measure of productivity comes from the TOPS/PALMS initiative, wherein they used satellite imagery to document, on a yearly basis from 2001-2010 several landscape factors including Vegetation Productivity and phenology. Both of these variables are of interest to the NRCA as they provide some of the only available measures of trend at the ecosystem level. The results, which the TOPS/PALMS team has posted to a website titled "Ecocast", contain considerable variation from year to year. We expect that strong interannual variation in precipitation should drive variation in gross primary productivity (GPP). Thus, it is likely to take a long time series to detect significant trends, if GPP does trend. At present, changes in GPP are not close to being statistically significant. However as gross measures of landscape change, they are still informative.

The TOPS/PALMS group reports vegetation productivity as a measure of cumulative growth for each year, and for each season. This metric is reported as Gross Primary Productivity (GPP; Kg Carbon/m$^{2)}$. These measures are for each year, and for the four seasons of each year. They are recorded for major physiognomic vegetation classes: Evergreen Needle leaf Forests, Mixed Forests, Deciduous Broadleaf Forests, Closed Shrublands, Open Shrublands, Woody Savannas, Savannas, Grasslands. The data are reported for a region called the 'SIEN PACE', which is very similar to the PACE boundary for which we report climate data above. For the SIEN PACE area, overall annual GPP is trending downwards at the rate of -0.0108 kg C/m^2 . However, it is more informative to look at the individual landcover classes that are reported (Table 23). Using this approach, it is apparent that the lower elevation vegetation types: grasslands, savannas, woody savannas, and open shrublands all show a decrease in productivity trend, while the mid- to upper-elevation types are showing an increase. If this trend can be further tracked, and if it becomes statistically significant, this would imply a decrease in plant productivity for these elevations. Such a decrease could potentially be tied to climate change. These trends are therefore of interest, and merit discussion by Parks management as to what if any monitoring of such trends might be possible.

Table 23. The Gross Primary Productivity (GPP; kg/m2) for the SIEN PACE region. Values derived from satellite measures in 2001 and 2010 are shown. However, due to the noise in the data none of the reported landcover types shows a significant trend.

	Pixel count	2001	2002	2003	2004	2005	2006	2007	2008	2009	Slope
SIEN PACE	36821	1.97	1.07	1.04	1.84	2.07	1.90	1.25	1.32	1.61	0.00
SIEN Evergreen needleleaf forest	9329	2.36	1.16	1.20	2.15	2.25	2.15	1.68	1.71	2.11	0.03
SIEN Mixed forests	1765	2.60	1.37	1.29	2.47	2.77	2.52	1.96	1.91	2.44	0.04
SIEN Closed shrublands	300	1.67	0.71	0.67	1.69	1.96	1.73	1.09	1.18	1.46	0.02
SIEN Open shrublands	4323	1.29	0.60	0.57	1.25	1.38	1.27	0.68	0.86	1.03	0.00
SIEN Woody savannas	9697	2.04	1.15	1.07	2.00	2.43	2.17	1.27	1.32	1.60	-0.01
SIEN Savannas	3039	2.39	1.78	1.60	2.12	2.71	2.37	1.35	1.37	1.77	-0.07
SIEN Grasslands	5346	1.32	0.68	0.72	1.15	1.06	1.05	0.62	0.79	0.91	-0.03
SEKI	3504	0.71	0.24	0.28	0.58	0.59	0.59	0.40	0.45	0.55	0.00
SEKI Evergreen needleleaf forest	866	1.04	0.35	0.40	0.82	0.83	0.85	0.62	0.66	0.84	0.01
SEKI Mixed forests	139	1.20	0.43	0.34	1.12	1.21	1.15	0.87	0.84	1.03	0.03
SEKI Open shrublands	410	0.35	0.11	0.13	0.27	0.25	0.25	0.17	0.20	0.23	0.00
SEKI Woody savannas	484	0.68	0.21	0.26	0.61	0.66	0.64	0.36	0.41	0.46	0.00

Water Yield

Values of water yield from the SSP (2010) varied from 0 – 14 acre-feet on an annual basis (Figure 38). These values for water yield include all water that does not evapotranspire from the system. This differs from the runoff data presented earlier in that it includes storm runoff, baseflow, and deep groundwater. The quartile breaks for these data are: 0% = 0; 25% = 3.5; 50% = 7; 75% = 10.5; and 100% = 14. For the landscape, the area in each category is listed in Table 24.

Water yield may be of particular interest in discussions with planning entities from the Central Valley interested in the ecosystem services that the PACE region provides. Water yield is also a metric that can potentially be easily measured, which would permit the monitoring of future conditions under climate change.

Table 24. Area in each quartile of water yield for the PACE and SEKI extents, in acre-feet.

	PACE		**SEKI NP**	
Classes (acre-feet)	**Area (km^2)**	**Percent**	**Area (km^2)**	**Percent**
0 – 3	15,865.8	35.1	122.1	3.5
4 – 7	18,961.6	41.9	2,033.2	58.0
8 – 10	8,352.2	18.5	1,270.8	36.3
11 – 14	1,482.8	3.3	77.4	2.2
No Data	540.4	1.2	0	0.0

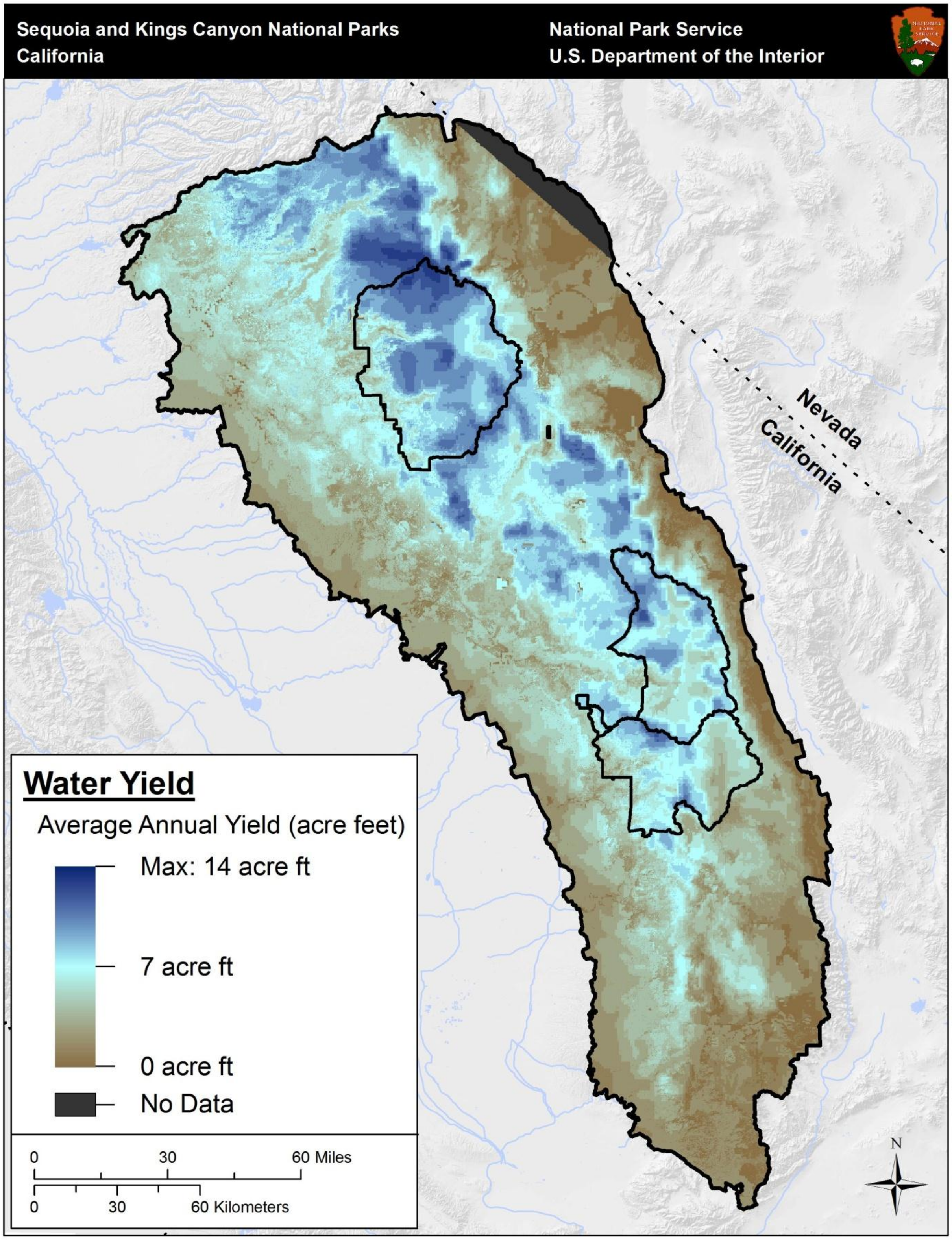


Figure 38. Water yield in acre-feet from 1971-2000 in the PACE Southern Sierra region

2. Human Land Use Data

This section provides a brief overview of land ownership patterns within the PACE region, as well as trends in population growth and development. Other chapters in this report cover additional resources that are impacted by human development, such as air quality and water quality.

Land Ownership

Forty five percent of the PACE region is made up of US National Forest System lands, 14.5% is found on National Park Service lands, and 29.3% is composed of privately held lands (Table 25), as determined from US GAP Analysis data (NPS 2011d, USGS Gap Analysis Program 2011). The PACE region intersects with 10 counties (Figure 39), for which population and housing trends are presented below. SEKI, however intersects with just two of those 10 counties (Fresno and Tulare). Unlike Yosemite National Park, SEKI does not have a buffer of US Forest System land to its west. As a consequence, there is a greater potential for exurban growth to abut the park and impact park boundary management.

Table 25. The extent of lands in the PACE region under different land ownership. SEKI is 3502.8 km^2, and constitutes 54% of the National Park lands in the region. The GIS also indicates that there are 35 km^2 of inholdings within the SEKI NP boundary.

	Area (km^2)	**Percentage**
National Park Service (NPS)	6,532.1	14.5%
Bureau of Land Management (BLM)	3,477.9	7.7%
Bureau of Reclamation (BOR)	166.5	0.4%
County Land or Regional Agency Land	41.8	0.1%
Department of Defense (DOD)	319.0	0.7%
Fish and Wildlife Service (FWS)	3.6	0.0%
State Parks and Recreation	34.8	0.1%
National Forest System (USFS)	20,328.8	45.0%
Tribal Land	225.7	0.5%
City Land	385.3	0.9%
Other Federal	7.8	0.0%
Private Conservation	53.8	0.1%
State Fish and Wildlife	127.0	0.3%
Other State	267.9	0.6%
Private Unprotected	13,230.8	29.3%
Total	**45,203.0**	**100.0%**

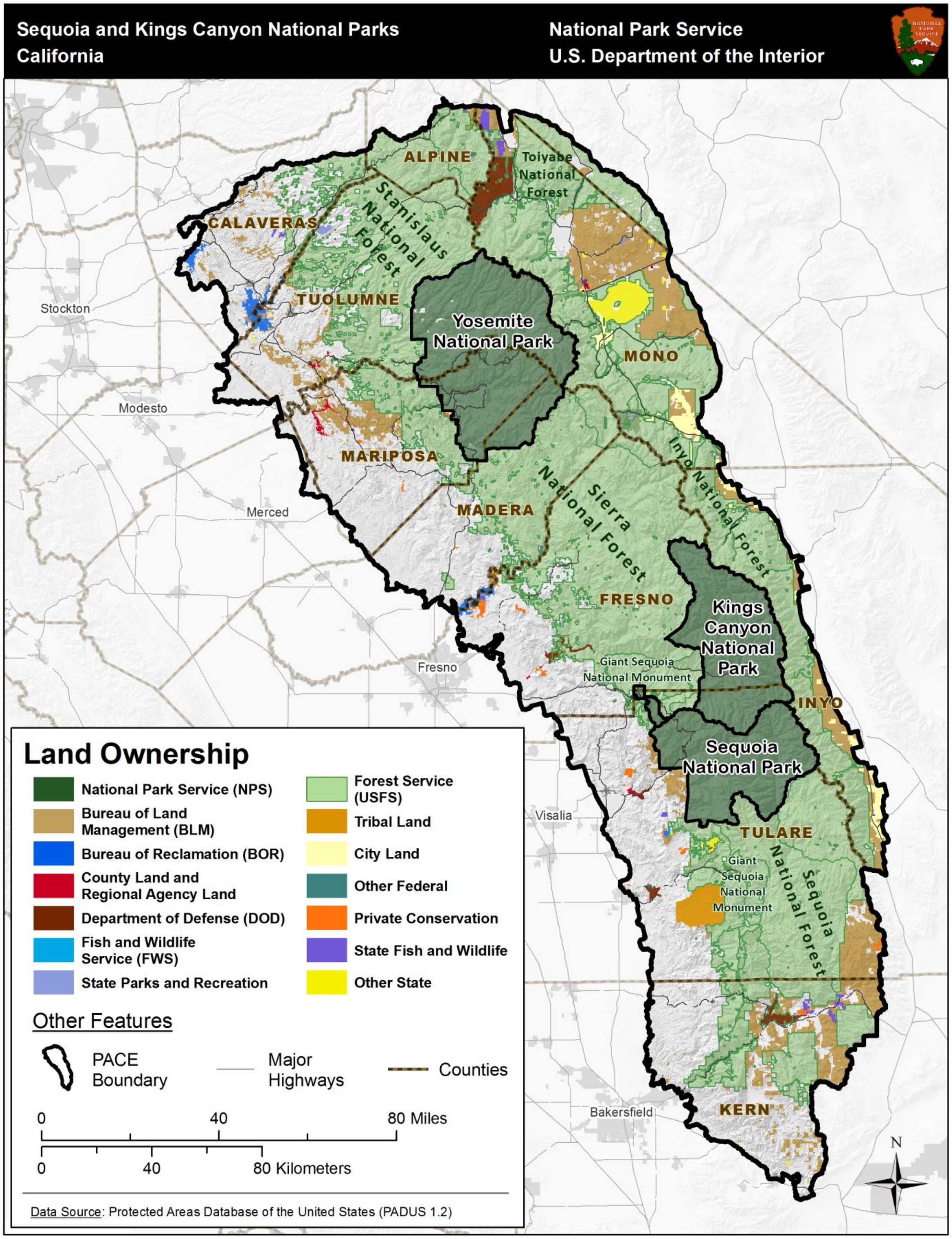


Figure 39. The extent of lands in different ownership classes within the PACE boundary.

Population Trend by County

The population of the region can be traced by decade at the county level. These data are developed by the National Park Service (Waisanen and Bliss 2002, NPS 2010a). Of the ten counties in the PACE region, Fresno and Tulare counties, in which SEKI NP is found, are among the three fastest growing (Figure 40). The 2010 population numbers (US Census) are: Alpine 1,175; Calaveras 45,578; Fresno 930,450; Inyo 18,546; Kern 839,631; Madera 150,865; Mariposa 18,251; Mono 14,202; Tulare 442,179; Tuolumne 55,365.

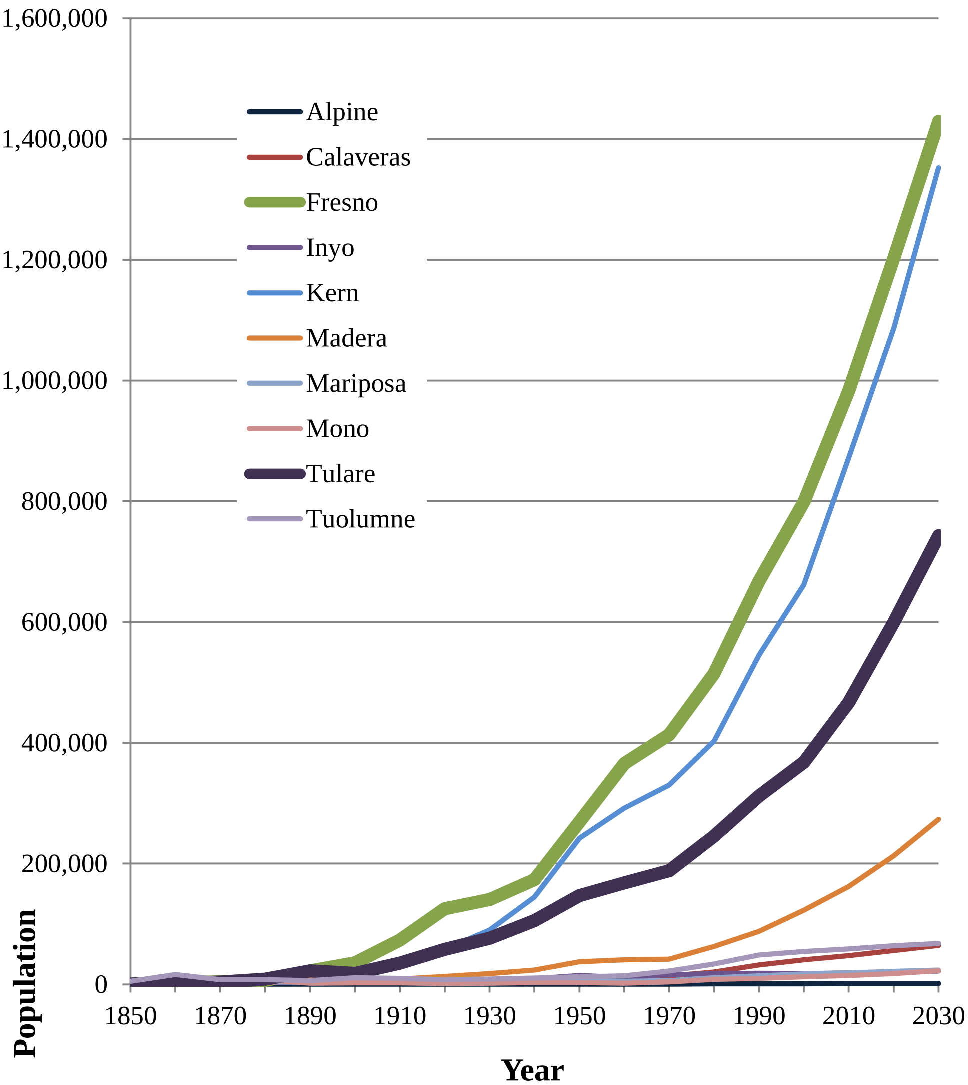
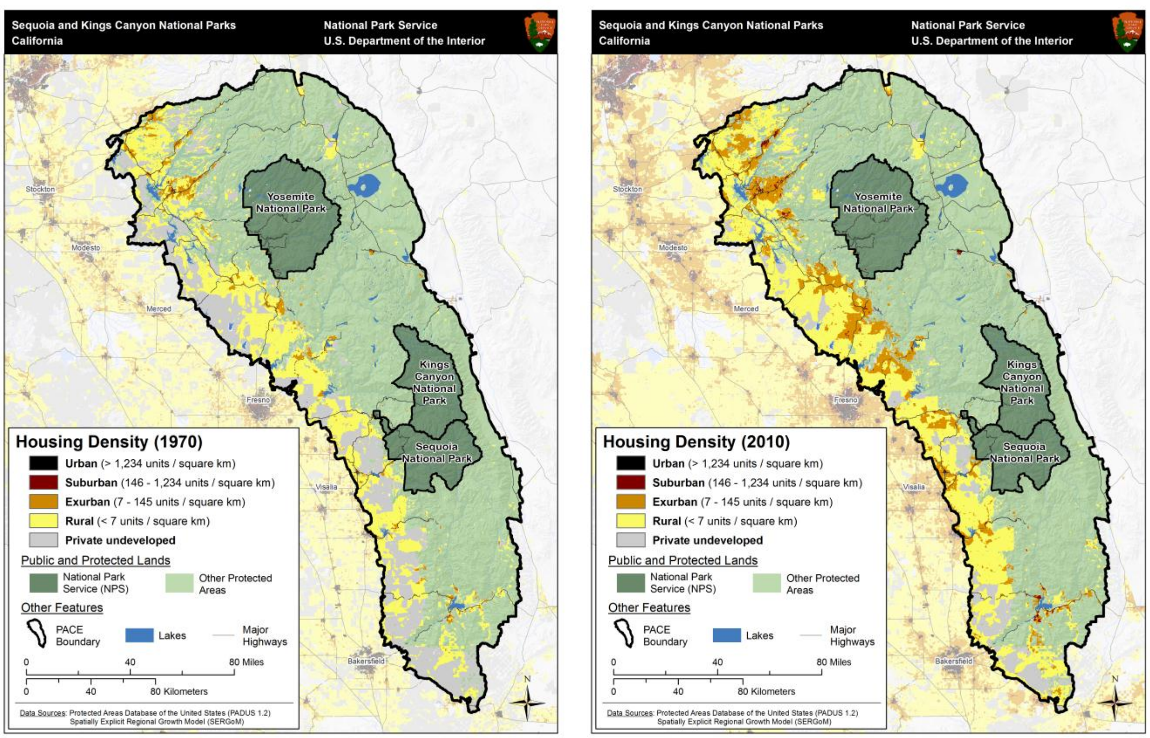


Figure 40. The trend and projected population for the ten counties in the PACE region. The two counties in which SEKI is found, Fresno and Tulare, are highlighted with bold-faced lines and represent two of the three counties with the largest populations and most rapidly growing populations.

Housing Density

According to the spatially explicit regional growth model (SERGoM, Theobald 2005, NPS 2010b), the foothills region below the park has experienced extensive urban growth over the past 40 years (Figures 41, 42 & 43), particularly rural dwellings (< 7 units / km^2) have expanded by 3,739 km^2 in the PACE region (Table 26). Additionally, 2061 km^2 of rural land holdings have transitioned to the next denser level of housing, 'exurban', comprised of 7-145 dwellings / 1 km^2. Rural building over this time has occupied over 67% of all private undeveloped land within the PACE boundary. The majority of this growth has occurred along Highway 49, in the Gold Country. While this growth does not directly impact the Parks, it does impact the vegetation and fauna where it occurs.

To identify the broad vegetation types that were impacted by this development, the areas which experienced a transition to higher density development categories were overlaid on the Kuchler Map of Potential Natural Vegetation for California. This map was originally published with the first edition of the Terrestrial Vegetation of California (Barbour and Major 1977). The Kuchler Map was selected for this analysis because it potentially represents historic vegetation conditions in the developed areas. Table 27 lists the amount of area impacted by development, broken out by vegetation type. Types which are typically found at lower elevations, such as Blue Oak – Foothill Pine Forest and California Prairie, experienced the majority of the development. Areas in the Sierra Nevada that have experienced significant amounts of human settlement are known to have reduced canopy cover, a higher proportion of exotic trees, and increased coverage of impervious surfaces (McBride et al. 1996). In addition to the conversion of wildlife habitat, these changes can increase fire hazards and alter forest hydrology.



Figures 41 & 42. Housing density in the PACE region in 1970 and 2010.

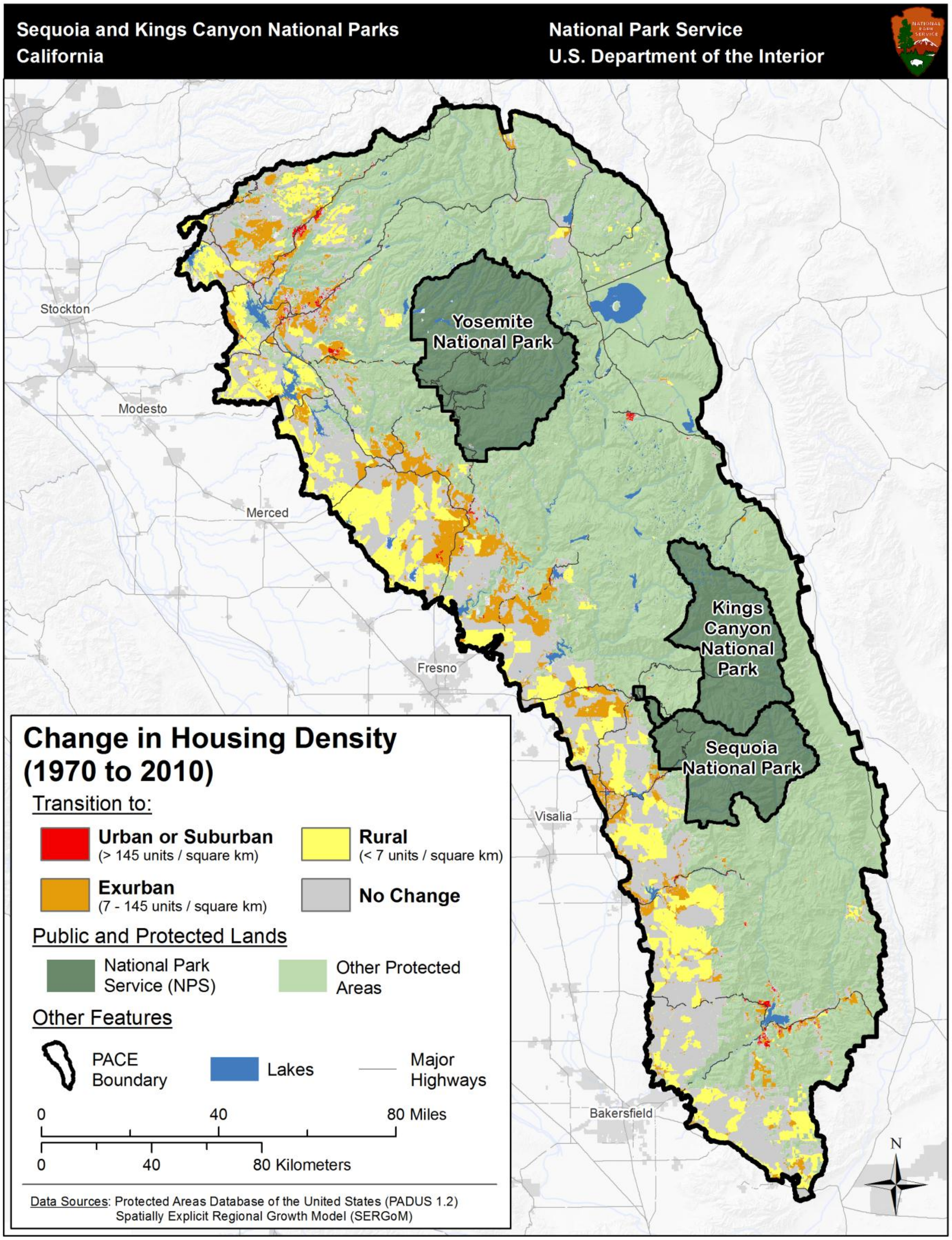


Figure 43. Change in extent of lands in different housing density classes within the PACE boundary**.**

Table 26. A transition matrix showing the square kilometers of land that have converted from one type of private lands to another between 1970 (rows) and 2010 (columns). Numbers in italics below the diagonal represent the likely level of map error, since we assume that no denser human habitations are becoming less dense. The bold faced value highlights the change of private undeveloped that land that has become rural residential land.

Classes	**Total (1970)**	Urban-Regional Park	Private undeveloped	Rural	Exurban	Suburban	Urban
Urban-Regional Park	21	21	-	-	-	-	-
Private undeveloped	5,628	-	1,802	**3,739**	86	1	-
Rural	6,402	-	*10*	4,320	2,061	11	0.1
Exurban	780	-	*1*	*10*	670	98	1
Suburban	30	-	*0*	*0*	*2*	24	4
Urban	11	-	-	-	*0*	*0.1*	11
Total (2010)	12,872	21	1,813	8,069	2,819	134	16

Table 27. Area of land affected by recent development in the PACE region, in km^2. These numbers exclude the small portion of the PACE which is in Nevada, as the Kuchler Map of Potential Natural Vegetation only covers California. Additional Exurban and Suburban/Urban growth between 1970 and 2010 is presumed to be densification on Rural lands, rather than development of natural landscapes.

Description	**Total Area in PACE**	**Total on Private Lands**	**Area Developed to Rural by 1970**	**Additional Rural by 2010**	**Area Developed to Exurban by 1970**	**Additional Exurban by 2010**	**Area to Suburban / Urban by 1970**	**Area to Suburban / Urban by 2010**
Juniper - Pinyon Woodland	2,561.1	249.2	168.3	47.1	13.4	42.9	0.5	1.3
Sierran Montane Forest	6,851.1	481.8	200.3	199.0	49.6	48.7	3.4	4.8
Upper Montane - Subalpine Forests	9,123.0	49.7	26.8	1.9	16.4	6.2	4.5	6.5
Blue Oak - Foothill Pine Forest	10,608.1	8,217.4	4,298.2	2,310.1	390.0	1,475.3	17.1	53.0
Riparian Forest	8.6	7.4	3.3	0.0	2.9	3.1	1.2	1.6
Chaparral	2,292.3	670.9	339.9	156.4	36.7	123.0	0.4	1.8
Northern Jeffrey Pine Forest	2,064.3	43.0	14.8	12.8	1.2	1.2	0.1	0.1
Sagebrush Steppe	2,202.4	207.5	131.7	43.8	14.2	22.9	0.9	1.0
Valley Oak Savanna	126.8	122.2	67.3	24.3	11.1	28.3	0.1	0.3
California Prairie	1,962.9	1,830.3	628.5	778.7	67.1	173.6	7.9	19.4
Alpine Communities And Barren	2,788.0	1.8	0.6	0.1	1.2	0.0	0.0	0.0
Joshua Tree Scrub	29.4	27.1	5.9	10.0	0.0	0.4	0.0	0.0
Mojave Creosote Bush	73.9	11.4	3.8	7.2	0.4	1.0	0.0	0.0
Blackbush Scrub	286.8	3.3	3.1	0.0	0.1	0.0	0.0	0.0
Desert Saltbush	67.1	0.2	0.2	0.0	0.0	0.0	0.0	0.0
Sierran Yellow Pine Forest	3,269.5	865.2	501.0	148.1	173.3	219.8	5.4	24.6

3. Conservation Context

This section provides additional context on the PACE region from the perspective of conservation planning, and presents several additional measures of potential conservation interest.

Gap Status

Land management classes in the US GAP Analysis program represent 4 levels of land management from the perspective of conservation. Levels 1-3 are typically some sort of government lands and range from the highest level of biodiversity protection in GAP 1 to multiple extractions permitted on GAP 3. GAP 4 identifies lands which do not have a recognized mandate for protection. The GAP Status of lands within the PACE boundary are shown in Figure 44, and the area of land within each category is given in Table 28. The values for GAP status codes 1, 2, and 3 were extracted from the Protected Areas Database of the United States (PAD-US, Gap Analysis Program 2011). GAP status 4 was calculated as the remaining area within the PACE, which had no known mandate for protection. This area is similar to the private undeveloped and developed lands identified by the Spatially Explicit Regional Growth Model in the previous section, but derives from a different source. It also differs slightly from the 13,231 km^2 identified as privately held unprotected land, in Table 26, because some publicly help lands, such as Department of Defense land, are classified under GAP status 4. Since the SEKI NP lands have the highest level of protection, they form a contribution to the PACE region of that class. However, because of the wilderness areas on the USFS lands, and Yosemite NP to the north, SEKI NP contributes about 25% of the GAP code 1 to the region's conservation profile.

Table 28. Area in each GAP Status Code for the PACE and SEKI extents, in km^2.

	PACE		SEKI NP	
GAP Status Code	**Area (km^2)**	**Percent**	**Area (km^2)**	**Percent**
1	14,325.7	31.7	3,502.9	100
2	2,068.6	4.6	0	0
3	15,001.5	33.2	0	0
4	13,807.1	30.5	0.7	0

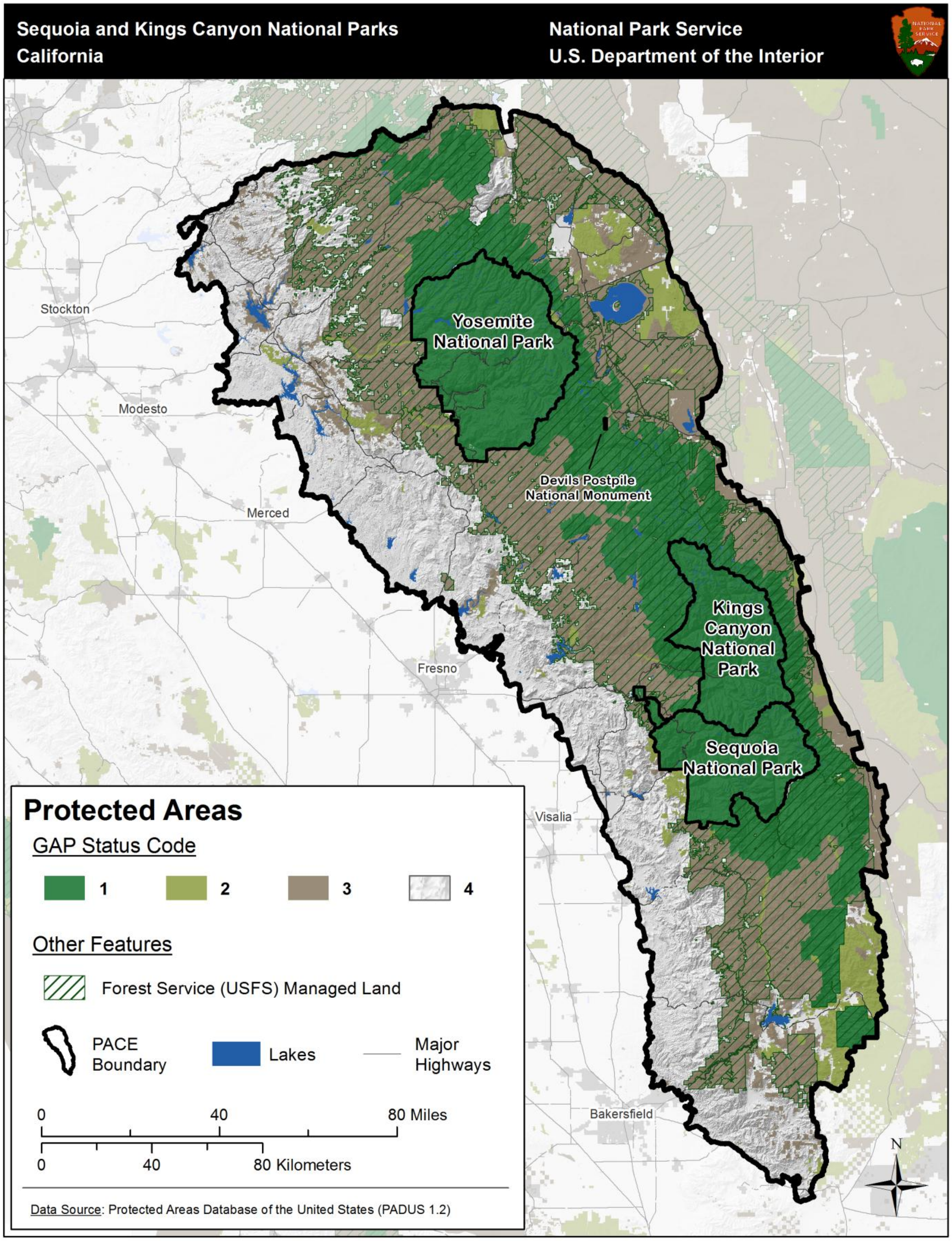


Figure 44. The PACE landscape broken up according to GAP land management classes.

Connectivity

Landscape connectivity, the uninterrupted continuation of natural habitats between habitat patches, is increasingly considered an important ecological objective in conservation planning. There are several landscape connectivity exercises that have been conducted for the PACE region. We selected a California State-sponsored connectivity study from the Essential Habitat Connectivity Project (CEHC: http://www.dfg.ca.gov/habcon/connectivity/; Spencer et al. 2010), and a model by David Theobald (Theobald et al. in review) produced at the national scale, to portray important linkages in the region.

The CEHC maps used a least cost corridor approach (e.g., Rouget et al. 2006) to develop potential corridors crossing the landscape, which represent areas within which some connectivity should be maintained. These zones, shown in tan in Figure 45 mostly address elevational connections between the large federal lands of the southern Sierra, and the Central Valley or Sierra Foothill regions. Least cost corridor modeling assesses the landscape and ranks the area between two target locations in terms of the ease of travel through that area. Factors such as less distance, fewer roads, more suitable habitat, less inhospitable terrain, and flatter topography can all be used to rank an area. The corridors show within them the best option as a light colored, low cost path, with less suitable spatial options along the margins in tan.

The Theobald connectivity map identifies connections between the least human-impacted regions of the United States. The landscape is ranked using an index of “naturalness” which is used to represent general landscape permeability. However, rather than identifying discrete habitat patches ahead of time, the pathways are created using an approach based on percolation theory, which grows clusters from random starting locations, much like water flowing across a surface. This allows the general pattern of landscape connectivity to be characterized, without the need to arbitrarily define core habitat areas. The thicker lines (Figure 45) represent corridors with higher levels of flow across the permeability surface. These corridors are important in maintaining regional connectivity. The percentage classes shown in the map represent how a corridor ranks nationally in terms of its accumulated flow. For example, the 95-100% class includes the lines which have a higher flow volume than 95% of the other lines.

Many of the larger corridors identified using the Theobald approach occur between the high elevation protected areas of the Southern Sierra and the relatively undeveloped areas to the east. Additionally, a major corridor is shown running to the south across the Tehachapi Mountains, and there are many smaller corridors running in a roughly east-west orientation along the western slope of the Sierra.

Since both approaches identify a need, but are not spatially explicit about where conservation or preservation actions should be, the images in the section are not accompanied by tables describing the area within corridors, or area needed. Rather, these images should be considered a guide for future work for those interested in maintaining the landscape connectivity of this region.

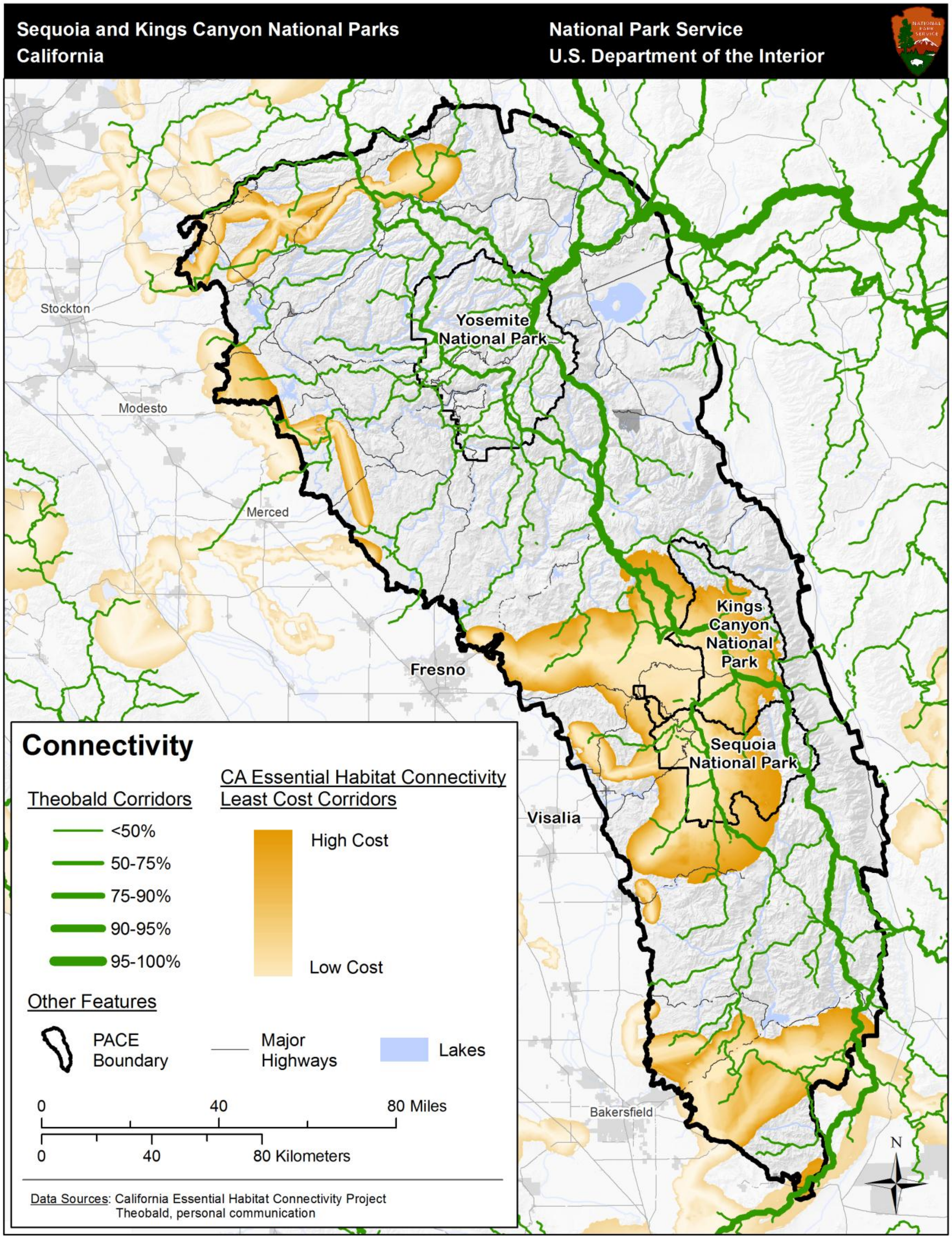


Figure 45. Landscape connectivity as modeled in two studies, for the PACE region.

Landscape Fragmentation

Landscape fragmentation is a measure of the level of ecological disruption occurring on the landscape. We examined fragmentation by roads in the PACE region, and by roads plus trails within SEKI NP. At the PACE level, we used all roads to look at fragmentation, and buffered roads by 500 m (Figure 46) to account for their indirect and cumulative impacts on habitat quality (NPS 2011b). At the SEKI NP level, we buffered roads by 500 m, maintained trails by 100 m and unmaintained trails by 50 m (Figure 47). The resulting patch size distributions were then classified using the Jenks natural breaks algorithm, which is the default method for classifying quantitative data in the ArcGIS software. The algorithm is designed to maximize the difference between classes based on natural groupings in the data. It was used to get a good representation of the range of values within each area. The classes do not have any specific ecological significance. The same method was used for both the PACE and the SEKI areas, but the classes are different, because they are specific to each dataset. The landscape patch size distribution for the PACE region shows that 35%, and for SEKI NP almost 92%, are in the least fragmented conditions (Table 29). In contrast to the map of land ownership, landscape fragmentation on the western border of SEKI looks fairly favorable, with relatively few roads and trails. In contrast, the western border of Yosemite, despite being in USFS ownership, appears more heavily fragmented than SEKI.

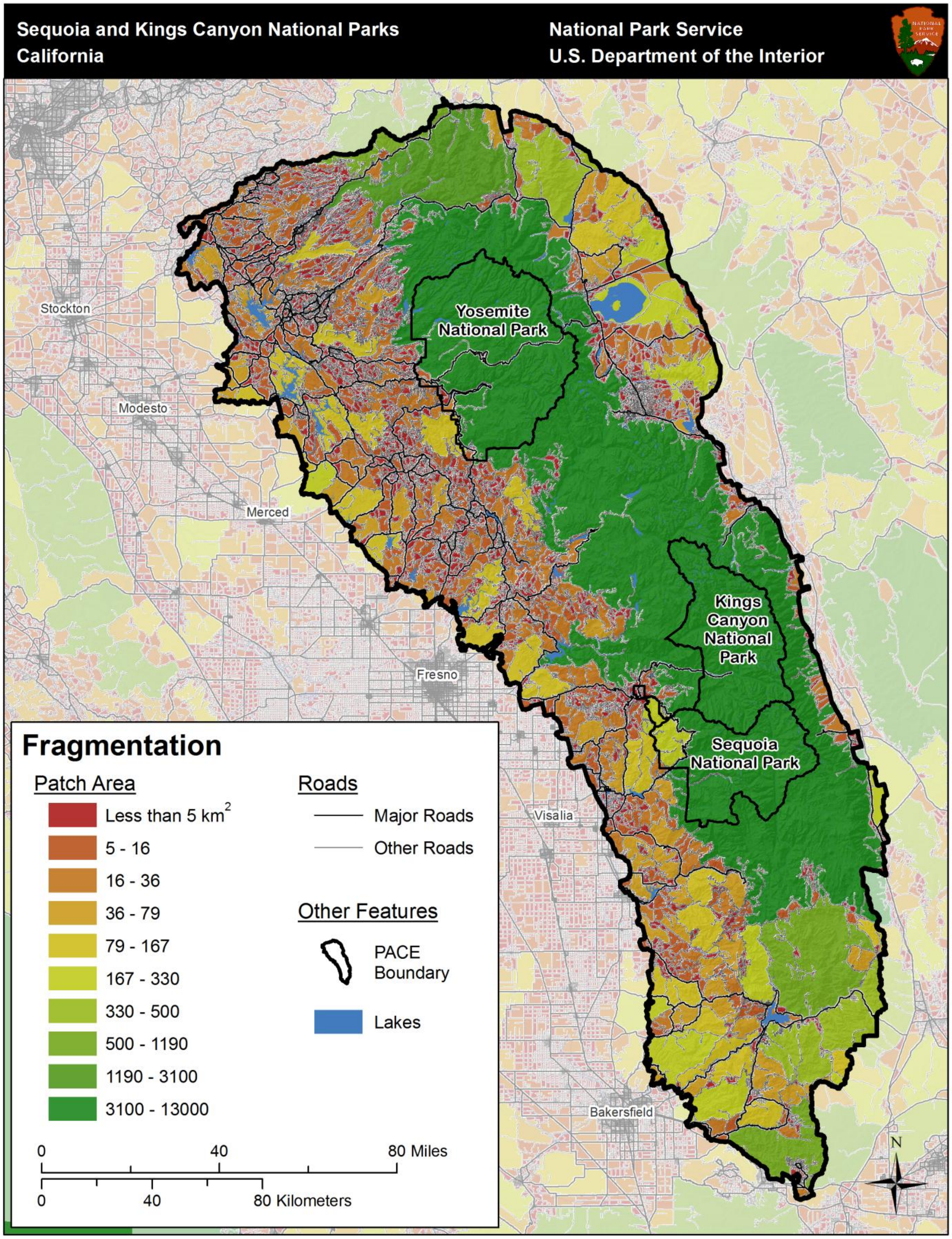


Figure 46. The distribution of landscape patches as fragmented by roads in the PACE and SEKI boundaries.

Table 29. Fragmentation in PACE (all Roads). The number of landscape patches that occur in different area classes for the PACE and SEKI boundaries. 'Total Area' refers to the area of all patches that intersect the given boundary, and 'Area In…' refers to the area of those same patches, but when cut at the edge of the management unit.

	PACE			SEKI			PACE	SEKI
Size Class (km^2)	**Number Of Patches**	**Total Area (km^2)**	**Area In PACE (km^2)**	**Number Of Patches**	**Total Area (km^2)**	**Area In SEKI (km^2)**	**Percent**	**Percent**
0 – 5	3,987	1,622.3	1,573.9	12	13.8	3.8	3.5%	0.1%
5 – 16	254	2,266.9	2,144.3	2	13.3	0.9	4.7%	0.0%
16 – 36	109	2,644.5	2,364.0	1	21.3	3.7	5.2%	0.1%
36 – 79	50	2,574.9	2,064.2				4.6%	0.0%
79 – 167	32	3,646.5	2,919.7	1	166.6	0.7	6.5%	0.0%
167 – 330	13	2,937.6	1,942.0	1	184.8	159.5	4.3%	4.6%
330 – 500	6	2,339.8	1,242.9				2.8%	0.0%
500 – 1,190	4	3,738.0	1,664.1				3.7%	0.0%
1,190 – 3,100	1	1,195.0	1,187.9				2.6%	0.0%
≥ 3,100	2	16,078.4	15,916.8	1	12,971.0	3,218.6	35.2%	91.9%

The distribution of landscape patches within SEKI NP identifies six patches within the Park that are not cut by even a trail that are over 123 km^2 (Figure 47, Table 30).

Table 30. Fragmentation by Roads and Trails in SEKI NP.

	SEKI		
Size Class (km^2)	**Number Of Patches**	**Total Area (km^2)**	**Percent**
0 – 1	188	15.1	0.4%
1 – 3	15	28.5	0.8%
3 – 7	15	66.1	1.9%
7 – 14	12	111.5	3.2%
14 – 24	8	161.0	4.6%
24 – 34	9	265.4	7.6%
34 – 45	3	126.3	3.6%
45 – 80	9	582.8	16.6%
80 – 123	5	502.6	14.4%
≥ 123	6	1,264.8	36.1%

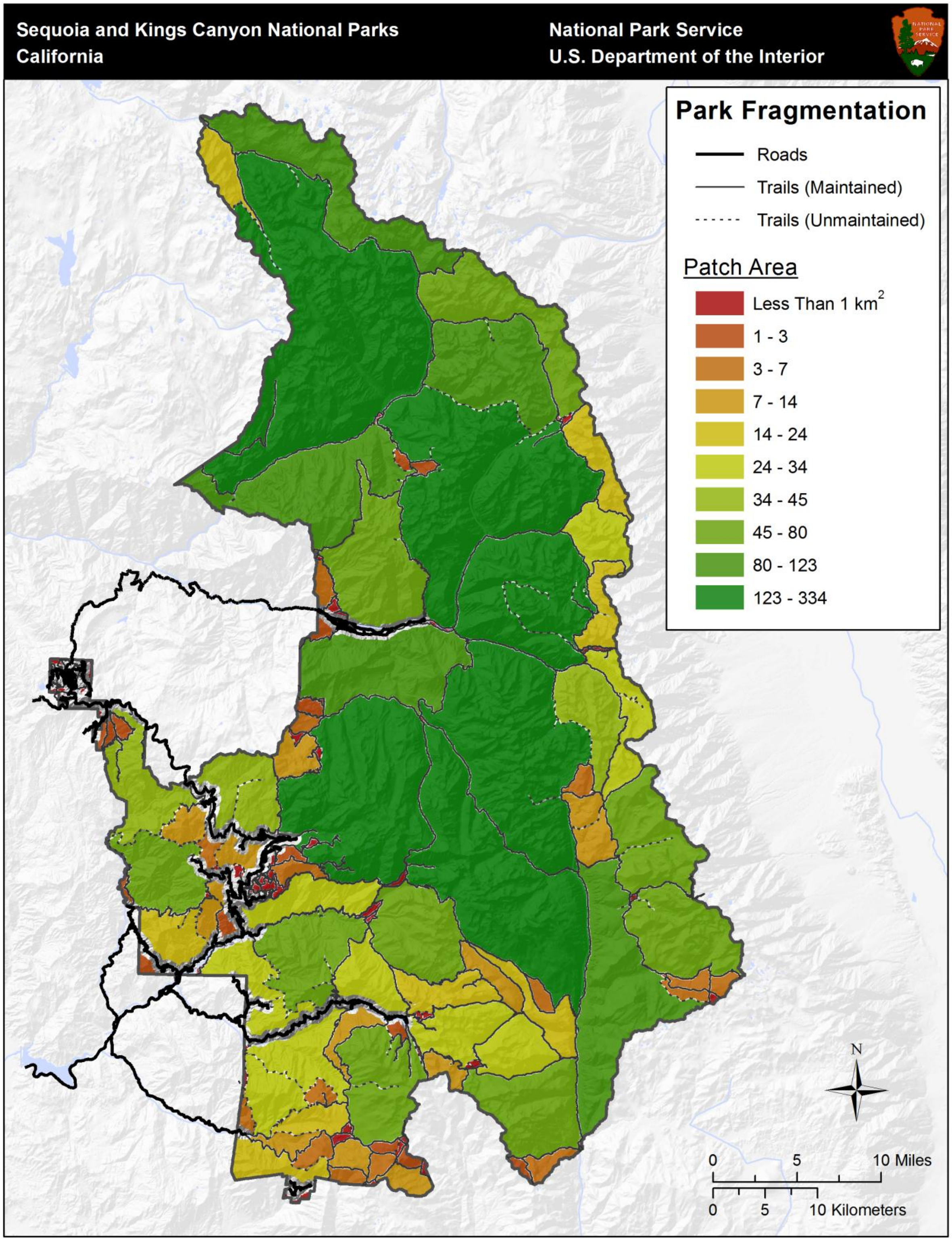


Figure 47. The distribution of landscape patches in SEKI NP, as fragmented by roads, and maintained and unmaintained trails. Roads carry a weight of 500 m, maintained trails of 100 m and unmaintained trails of 50 m. The intersections of these linear features is used to identify patches of habitat.

Fire Risk

The SEKI NP has developed a Fire Return Interval Departure (FRID) map that may be useful for assessment of change in fire risk under future climate change. The FRID index identifies the level of fire risk as measured by the Fire Return Interval Departure (FRID):

$$\text{Fire Return Interval Departure (FRID)} = \frac{(\text{TSLF} - \text{RI}_{\text{max}})}{\text{RI}_{\text{max}}}$$

in which,

> RI_{max} = maximum average return interval for the vegetation class (maximum values provide a conservative estimate)

and,

> TSLF (time since last fire) = time that has passed since the most recent fire based on historic fire records, or using a baseline date of 1899, derived from fire history chronologies of when areas last burned.

While this database does not cover the entire PACE region, we include a view of it here for reference (Figure 48). The class intervals used in the map were developed by SEKI scientists to capture current forest conditions, and the need for burning based on historic fire return intervals (Caprio and Graber 2000). A negative number in the FRID index indicates that the area has burned relatively recently, within the timeframe of its historic return interval. Positive values indicate areas where the time since last fire exceeds the historic return interval. Much of the low elevation lands to the west of SEKI NP appear to be far beyond the normal return interval for a wildfire. The suppression of wildfires and the subsequent alteration of forest structure and fuel loads has been the subject of previous reports (e.g., McKelvey et al. 1996). These high risk areas will need to be actively managed to reduce the severity of future fires.

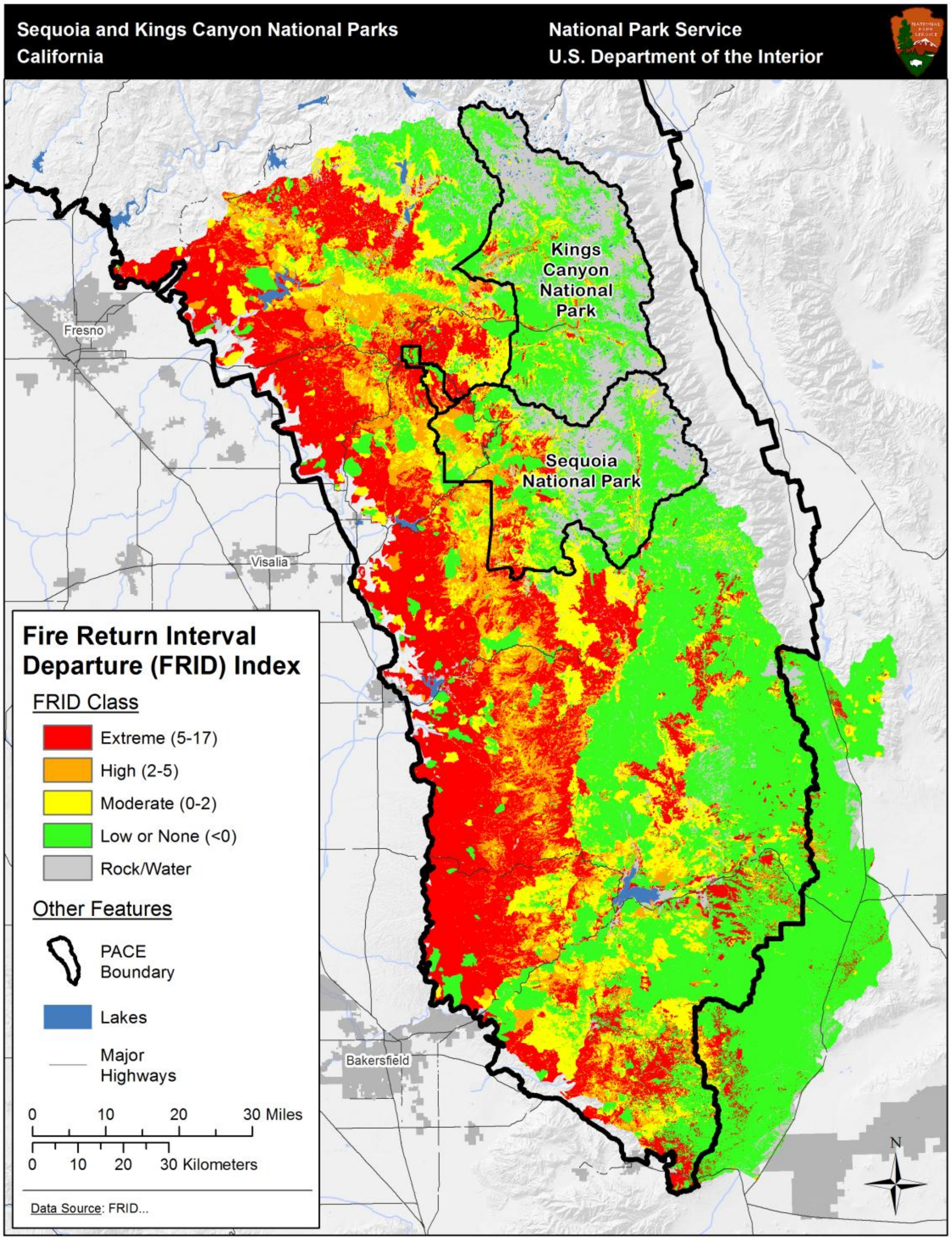


Figure 48. Fire Return Interval Departure (FRID) index.

Analysis Uncertainty

There are a number of sources of uncertainty entrained in the maps and analyses presented here. For the climate data, a major source of uncertainty comes from the native source of the PRISM data. The PRISM group is in the process of publishing a second edition, with native scale of 800 m grids. However, the timing of this project is such that we were not able to take advantage of the newer data published. While there has been no formal analysis to determine how different Tmax, Tmin, and Ppt rendered from weather station to a 4 km verses an 800 m grid scale has been produced, anecdotal accounts describe observable differences for some parts of California. In general, however, there are relatively few climate stations in and near the PACE region (Figure 49). In addition, montane landscapes are notoriously difficult to model as a consequence of the varying degree to which cold air drainage down canyons affects different portions of the landscape. Thus, these models of climate are somewhat what of an abstraction of a best estimate of spatial pattern in climate change. In addition, many of the climate values mapped here are derivative values estimated based on temperature and precipitation data. Composite values are bound to carry higher uncertainty than directly measured values, therefore maps of climatic water deficit, and other values derived from a combination of temperature, precipitation and other static environmental layers such as soils or geology, may have higher levels of error than the direct climate interpolations. We included these derivative environmental projections due to their ecological importance, with the idea that even if the numbers are not completely accurate, the maps provide an initial view of the variation of across the PACE area of important climate-ecologic variables. Finally, there are a few notable climate station problems that may influence the PACE region. Climate station sensors occasionally get moved. Moving a climate stations a few hundred meters can drive an artifactual climate change. Anecdotal information suggests that there are stations like this in the Sierra Nevada.

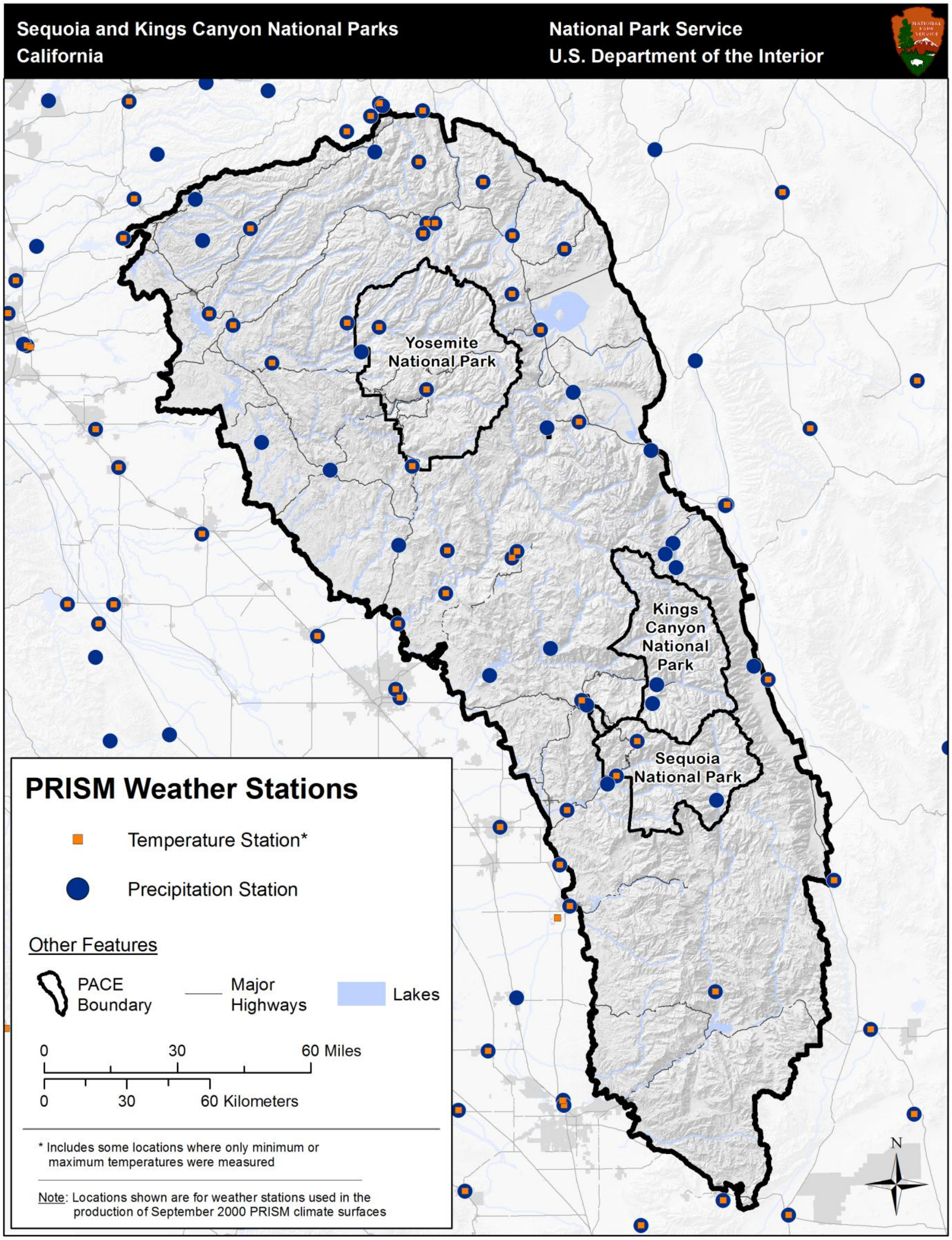


Figure 49. The locations of PRISM stations used for the September 2000 interpolation of weather values.

Similarly, the model of standing carbon is derived from a vegetation map with the Megagrams/ha estimated as one half the weight of the vegetation type in the map TNC's Dick Cameron, personal communication). These values should, therefore be more or less correct relative to each other, but may be systematically different from actual standing carbon stock.

Finally, synthetic ecological attributes, such as connectivity, as assessed by Theobald's least patch cost methods, are abstractions that simply connect patches of different sizes. In actuality, land cover types and the condition of those habitats matter quite a lot to most species. Species vary in their dispersal capacity. Thus, species are likely to find different dispersal paths through the PACE landscape.

In contrast, the land ownership, housing density, population size and other human impact coverages are likely to carry the lowest relative error among the data sets presented here. There are a number of governmental agencies requiring spatial data on human distributions, and this these data are spatially accurate and updated frequently.

Interactions with other focal resources

Most of the focal resources assessed in the NRCA interact with broader SEKI and PACE landscape. From air quality to species populations, focal resources have a landscape signature and interact with the landscape features described within this section of the report. As an example, many of the other focal resources in the SEKI NRCA (e.g., giant forest, old growth forest, air quality, invasive plants, biodiversity) might be influenced by the climate trends or the human stressors that are described in this chapter. For example, the loss of frozen nights in the previously winter frozen lower parts of the Parks may be having an effect on the vegetation described in the Foothills section by altering the phenology of the system in ways that are not yet detectable by remote sensing. Similarly, changes in climatic water deficit are predicted to impact vegetation types through altering fire frequencies. Maximum daily high are temperature quite clearly influences ozone production.

During the project span of this NRCA, the GIS analysts and landscape context group worked with the lead authors for each of the focal elements. The outreach included leading a discussion about what spatial extent and what watershed scale to use for the roll up condition maps produced for every other chapter; and to review how each focal group planned to conduct their own, resource specific, spatial analysis. Results in many of the other chapters were informed by these discussions, particularly for the landscape components of those analyses.

Stressors

The stressors listed in the other sections of this NRCA were focused on how they impact the Parks, specifically. This regional overview chapter provides context of trends in climate, and in human populations, detailed in the sections above. Air quality as a stressor was dealt with regionally in the air quality chapter. It was beyond the scope of this chapter to regionally address invasive species, altered fire regimes and new disease paradigms.

Stressors that are unique to this chapter primarily fall into two types: climatic change and human encroachment. With respect to human encroachment, impact from population growth in the central valley far exceeds potential impact from growth in the Owens valley. Private land encroaches to near the western park boundary, a management concern for the future of the parks. Despite high regional population growth and private lands abutting park boundaries, the roads coverage suggests that fragmentation on the western boarder remains relatively low.

Climate models predict strong changes in the climate of the Sierra Nevada, as shown in the maps for minimum and maximum temperature included in those sections. Using the best available data for reconstructing climate in the region, however, shows modest amounts of warming, and some non-intuitive assessments of cooling maximum daytime high temperatures. Increasing precipitation, coupled with cooler Tmax has limited the extent to which Climate Water Deficit has increased in the parks. Predictions of future climate, however, suggest an acceleration of warming through the 21st century that is likely to increase stress on vegetation, increase fire likelihood, and exacerbate air quality issues.

Assessment

The PACE region is comprised of over 50% federal lands, on which ecological conditions are generally good. However, both urban expansion on private lands and trends in climate-related variables are changing in the region. These changes likely will have ecological impacts on federal lands in the long term, and should be closely monitored.

As a complex montane environment, detection of change is made difficult by a relatively weak capacity to model climate surfaces with the kind of accuracy we might expect in simpler terrain. Nevertheless, the available data suggest that the climatic changes experienced within the SEKi landscape have been modest and do not suggest large magnitude shifts in vegetation. That said, the current land cover types were often established hundreds, if not thousands, of years ago. As a consequence, the climatic conditions under which those habitats established may have been under substantively different climatic conditions, as well as different fire regimes. It is difficult to assess the degree to which various land cover types are sensitive to cover type change as a consequence of disturbance in any way other than by experiencing those changes as they happen. So, while climate change has not been dramatic, we have a very limited capacity to determine if even modest change crosses tipping points for different cover types.

Level of confidence in assessment

Each regional assessment of dynamics within the PACE boundary is dependent on the maps produced by external data providers, with the exception of the climate surfaces and their derivative products presented here, which were produced by the authors. However, confidence in the maps provided by other agencies is generally high.

One exception are the trends reported for GPP by the TOPS/PALMS group. These measures report yearly vegetation dynamics as captured by MODIS imagery. The variation from year to year in these values means that even with 10 years of data, the variation is much greater than the declines measured, and no statistically significant trend is observable.

For vegetation maps, generally speaking a map accuracy of 80% or higher is considered good, in terms of the map being able to accurately represent the dominant vegetation on the landscape. We assume that the FRAP map has achieved this level of accuracy, while we know that the LANDFIRE map has not. However, the FRAP map is comprised of a mosaic of best available data and has no accuracy measure. The LANDFIRE map does not include an accuracy assessment report in its metadata, but does contain the caveat that the map should not be used for local applications (the assessment having been done post-hoc by NPScape). The SEKI vegetation map has an overall map accuracy level of 80% at the association level and 86% at the alliance level.

Gaps in understanding

A soils map is needed for the SEKI NP and PACE regions. This will help in understanding the relationship between precipitation and plant spatial dynamics. In a similar vein, tracking of ground water to understand the relationship of high-elevation infiltration to ground water in the San Joaquin Valley would permit better quantification of the ecosystem services provided by the park. Surface waters are already somewhat understood, but the subterranean component is rarely even considered.

Developing a better understanding of the relationships of temperature, precipitation, snowpack and soil moisture across the spatial domain of the park would be very helpful in interpreting the potential impacts of future climates.

Expanding the fire return interval departure (FRID) database to the extent of the PACE would be useful for understanding fire risks across the region.

Modeled distribution of vegetation types which could allow a more mechanistic understanding of the possible response of vegetation to climate change. One version of the type of vegetation model that might be useful was conducted by Vankat and Major (1982) and Urban et al. (2000), who proposed a gradient perspective of vegetation. There are other options for vegetation modeling, such Dynamic Global Vegetation Models (e.g., Lenihan et al. 2003), or using combinations of species distribution models (e.g., Loarie et al. 2009) for dominant plant species that comprise major vegetation types.

Recommendations for future study/research

Given that SEKI is a complex climatic landscape, predictions suggest strong change in the climate of the southern Sierra Nevada over the next century, and the ready availability of climate sensing capacity, we strongly recommend that the park deploy an array of ibutton (or similar sensors) climate data loggers to record temperature and humidity along key points within the park. Having park-specific data on temperature over a decade in order to compare these data to future PRISM coverages will be enormously valuable in assessing climate change in the park as well as biotic sensitivity to climatic change. Deploying arrays of microsensors in spatial pattern that also includes the locations existing weather stations would permit the development of the temperature associations between the more permanent weather monitoring locations and the rest of the landscape. This could potentially be developed through systematic micro sensor deployment in different parts of the Park for 1-2 years per rotation.

A soils map should be surveyed.

Literature Cited

Barbour, M., and J. Major, eds. 1977. Terrestrial Vegetation of California. New York, NY: Wiley Interscience.

Bierwagen, B., D. M. Theobald, C. R. Pyke, A. Choate, P. Groth, J. V. Thomas, and P. Morefield. 2010. National housing and impervious surface scenarios for integrated climate impact assessments. Proceedings of the National Academy of Sciences 107: 20887-20892.

Caprio, C. A. and D. M. Graber. 2000. Returning Fire to the Mountains: Can We Successfully Restore the Ecological Role of Pre-Euroamerican Fire Regimes to the Sierra Nevada? USDA Forest Service Proceedings RMRS-P-15-VOL-5: 233-241.

Davis and Hansen, in review. Land-use change around US National Parks. Ecological Applications.

Environmental Systems Research Institute (ESRI). 2010. U.S. and Canada Detailed Streets. Compiled by Tele Atlas North America (2005), Inc., distributed by ESRI. Redlands, CA. DVD.

Flint, A.L., and Flint, L.E., 2007, Application of the basin characterization model to estimate in-place recharge and runoff potential in the Basin and Range carbonate-rock aquifer system, White Pine County, Nevada, and adjacent areas in Nevada and Utah: U.S. Geological Survey Scientific Investigations Report 2007-5099, 20 p. http://pubs.usgs.gov/sir/2007/5099/

Forman, R. T. T. and L. E. Alexander. 1998. Roads and their major ecological effects. Annual Review of Ecology and Systematics 29:207-231.

FRAP 2002. Methods for Development of Habitat Data: Forest and Range 2002 Assessment. Fire and Resource Assessment Program, Sacramento, CA. landcover map (http://frap.cdf.ca.gov/data/frapgismaps/select.asp)

Gross, J.E., A.J. Hansen, S.J. Goetz, D.M. Theobald, F.M. Melton, N.B. Piekielek, and R.R. Nemani. In press. Remote sensing for inventory and monitoring of the U.S. National Parks. Pages 29-56 in Y.Q. Yang (ed.), Remote Sensing of Protected Lands. Taylor & Francis, Boca Raton, FL.

Gross, J. E., L. K. Svancara, and T. Philippi. 2009. A Guide to Interpreting NPScape Data and Analyses. NPS/IMD/NRTR—2009/IMD/XXX. National Park Service, Fort Collins, Colorado.

Groves C. G. 2003. Drafting a Conservation Blueprint. Washington (DC): Island Press.

Hansen, A.J., C. Davis, N.B. Piekielek, J.E. Gross, D.M. Theobald, S.J. Goetz, F.M. Melton, R. DeFries. In press (2011). Delineating the ecosystems containing protected areas for monitoring and management. BioScience.

LANDFIRE. 2010. Homepage of the LANDFIRE Project. http://www.landfire.gov/ (accessed 20 January 2011).

Lenihan, J. M., R. Drapek, D. Bachelet, R. P. Neilson. 2003. Climate change effects on vegetation distribution, carbon and fire in California. Ecological Applications 13;1667-1681.

Lindenmayer D. B. and J. F. Franklin. 2002. Conserving Forest Biodiversity: A Comprehensive Multiscaled Approach. Washington (DC), Island Press.

Loarie, S.R., P.B. Duffy, H. Hamilton, G.P. Asner, C.B. Field, D.D. Ackerly. 2009. The velocity of climate change. Nature 462:1052-U111.

McBride, J. R., W. Russell, S. Kloss. 1996. Impact of Human Settlement on Forest Composition and Structure. Sierra Nevada Ecosystem Project, Final Report to Congress, Vol. II. Assessments and Scientific Basis for Management Options. Centers for Water and Wildland Resources, University of California, Davis, CA, pp. 1033–1040.

McDonnell, M. J. and A. K. Hahs. 2008. The use of gradient analysis studies in advancing our understanding of the ecology of urbanizing landscapes: current status and future directions. Landscape Ecology 23:1143-1155.

McKelvey, K. S., C. N. Skinner, C. Chang, D. C. Erman, S. J. Husari, D. J. Parsons, J. W. van Wagtendonk, C. P. Weatherspoon. 1996. An Overview of Fire in the Sierra Nevada. Sierra Nevada Ecosystem Project, Final Report to Congress, Vol. II. Assessments and Scientific Basis for Management Options. Centers for Water and Wildland Resources, University of California, Davis, CA, pp. 1033–1040.

National Academy of Public Administration. 2010. Strengthening America's best idea: an independent review of the National Park Service's Natural Resource Stewardship and Science Directorate. http://www.napawash.org.

National Park Service. 1999. Natural resource Challenge: The National Park Service's action plan for preserving natural resources.

National Park Service. 2010a. NPScape population measure – phase 1 metrics processing SOP: Current population total and density, historic population density, and projected population density. National Park Service, Natural Resource Program Center. Fort Collins, Colorado. Natural Resource Report. NPS/NRPC/IMD/NRR—2010/254. Published Report-2165453.

National Park Service. 2010b. NPScape housing measure – phase 1 metrics processing SOP: Current housing density, historic housing density, and projected housing density metrics. National Park Service, Natural Resource Program Center. Fort Collins, Colorado. Natural Resource Report. NPS/NRPC/IMD/NRR—2010/251. Published Report-2165448.

National Park Service. 2010c. NPScape landcover measure – phase 1 metrics processing SOP: Landcover area per category, natural vs. converted landcover, landcover change, and impervious surface metrics. National Park Service, Natural Resource Program Center. Fort Collins, Colorado. Natural Resource Report. NPS/NRPC/IMD/NRR—2010/252. Published Report-2165449.

National Park Service. 2010d. NPScape pattern measure – phase 1 metrics processing SOP: Landscape morphology metrics. National Park Service, Natural Resource Program Center. Fort Collins, Colorado. Natural Resource Report. NPS/NRPC/IMD/NRR—2010/253. Published Report-2165452.

National Park Service. 2011a. NPScape: monitoring landscape dynamics of US National Parks. Natural Resource Program Center, Inventory and Monitoring Division. Fort Collins, Colorado. http://science.nature.nps.gov/im/monitor/npscape/ (April 2011).

National Park Service. 2011b. NPScape roads measure – Phase 2 road metrics processing SOP: Road density and distance from roads. National Park Service, Natural Resource Program Center. Fort Collins, Colorado.

National Park Service. 2011c. NPScape pattern measure – Phase 2 National Land Cover Data pattern metrics processing SOP. Forest and grassland density. National Park Service, Natural Resource Program Center. Fort Collins, Colorado.

National Park Service. 2011d. NPScape conservation status measure – Phase 2 Protected Areas Database of the United States metrics processing SOP: Protected area and ownership category metrics. National Park Service, Natural Resource Program Center, Fort Collins, Colorado.

Nemani, R., H. Hashimoto, P. Votava, F. Melton, W. Wang, A. Michaelis, L. Mutch, C. Milesi, S. Hiatt, M. White 2009. Monitoring and forecasting ecosystem dynamics using the Terrestrial Observation and Prediction System (TOPS). Remote Sensing of Environment 113: 1497-1509.

Piekielek, N.B., C. Davis and A. Hansen 2010. PALMS SOP - Analyzing Protected-area Centered Ecosystems. Inventory and Monitoring Program, Natural Resource Program Center, National Park Service, Fort Collins, CO. Ver 1.2.

Piekielek, N.B., C. Davis and A. Hansen 2011. PALMS SOP - Estimating Protected-area Centered Ecosystems. Inventory and Monitoring Program, Natural Resource Program Center, National Park Service, Fort Collins, CO. Ver 1.6.

Radeloff, V. C., S. I. Stewart, T. J. hawbaker, U. Gimmi, A. M. Pidgeon, C. h. Flather, R. B. hammer and D. P. Helmers. 2010. Housing growth in and near United States protected areas limits their conservation value. Proceedings of the National Academy of Sciences of the United States of America107:940-945.

Rouget, M., Cowling, RM, Lombard, AT, Knight AT, Graham IHK. 2006. Designing large-scale conservation corridors for pattern and process. Conservation Biology 20:549-561.

Sethi P. and G. Simons. 2005. Biomass Potential from California Forest and Shrublands Including Fuel Reduction Potentials to Lessen Wildfire Threat. Public Interest Energy Research, California Energy Commission, Sacramento, CA. Report # 500-04-004.

Spencer, W.D., P. Beier, K. Penrod, K. Winters, C. Paulman, H. Rustigian-Romsos, J. Strittholt, M. Parisi, and A. Pettler. 2010. California Essential Habitat Connectivity Project: A Strategy for Conserving a Connected California. Prepared for California Department of Transportation, California Department of Fish and Game, and Federal Highways Administration.

SSP (Southern Sierra Partnership). 2010. Framework for Cooperative Conservation and Climate Adaptation for the Southern Sierra Nevada and Tehachapi Mountains, California USA. 228 pages. The Nature Conservancy, San Francisco, CA.

Story M and Others. 2009. A Comparison of Available National-Level Land Cover Data for National Park Applications. NRPC-FC. Fort Collins, CO. Published Report-663958.

Svancara, L. K., R. Brannon, J. M. Scott, C. R. Groves, R. F. Noss and R. L. Pressey. 2005. Policy-driven versus evidence-based conservation: a review of political targets and biological needs. BioScience 55:989-995.

Theobald, D. M. 2005. Landscape patterns of exurban growth in the USA from 1980 to 2020. Ecology and Society 10:32. (online) www.ecologyandsociety.org.

Theobald, D. M. 2010. Estimating natural landscape changes from 1992 to 2030 in the conterminous US. Landscape Ecology 25:999-1011.

Theobald, D. M., S. J. Goetz, J. B. Norman, and P. Jantz. 2009. Watersheds at risk to increased impervious surface cover in the conterminous United States. Journal of Hydrologic Engineering 14:362-368.

Theobald, D., S. Reed, K. Fields, and M. Soule. *In review*. Connecting natural landscapes using a landscape permeability model to prioritize conservation activities in the US. Conservation Letters.

Urban, D.L., C. Miller, P.N. Halpin, N.L. Stephenson. 2000. Forest gradient response in Sierran landscapes: the physical template. Landscape Ecology 15:603-620.

US General Accounting Office. 1994. Activities outside park borders have caused damage to resources and will likely cause more. U.S. Government Printing Office, GAO/RCED-94-59.

USGS GAP Analysis Program. 2011. Protected Areas Database of the United States (PADUS) version 1.2 Geospatial Metadata. Last accessed February 28, 2011.

Vankat, J. L. 1982. A gradient perspective on the vegetation of Sequoia National Park, California. Madroño 29: 200-214.

Waisanen, P.J. and N.B. Bliss. 2002. Changes in population and agricultural land in conterminous United States counties, 1790-1997. Global Biogeochemical Cycles 16:1137-1156.

NPS 102/120975, June 2013

National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science
1201 Oakridge Drive, Suite 150
Fort Collins, CO 80525

www.nature.nps.gov

EXPERIENCE YOUR AMERICA ™